EFFECTS OF STIMULUS DISTANCE ON CHILDREN'S HANDWRITING COPYING PERFORMANCE

By

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By

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Copying tasks are routinely used for handwriting instruction. In a neuropsychological model of graphomotor skills, handwriting copying tasks are shown as requiring complex language, visual acuity, and motor skills. Although handwriting has been studied in diverse fields, the parameters for optimal copying performance have not been identified.

An alternating treatments single subject design was used to compare the effects of three stimulus distances on handwriting legibility. The effects on level, variability, and trend of letter formation and word spacing scores when the copying stimulus was placed in front of the subject at distances of 0.5 m, 3 m, and 6 m were investigated in 13 second grade boys who were identified by their classroom teachers as having handwriting problems. Three subjects had emotionally handicapping conditions, 4 subjects were identified as at-risk for learning problems, 5 subjects were not receiving special services, and 1 subject was in a program for the gifted.

A criterion-based handwriting checklist, Error Analysis of Children's Handwriting (EACH), was devised to assess letter formation and word spacing. Stimuli for copying consisted of 50-letter, nonword sentences. Stimulus sentences were written in black ink on white paper the size of regular writing paper and a chalkboard. Data from each subject were graphically displayed and analyzed for level (medians), variability (interquartile ranges), and trend (slope) through visual inspection of boxplots and line graphs.

Investigation of level, variability, and trend of letter formation and word spacing data did not identify 0.5 m, 3 m, or 6 m stimulus distances as being optimal for letter formation or word spacing in any of the subjects. Attentional, motor, visual, or unknown factors other than stimulus distance may affect copying performance. Further research is needed to determine if the clarity of the ink-printed words on the white paper compared to ordinary chalk-written words on a chalkboard may have enhanced handwriting legibility for 3 m and 6 m distances. Improvements in letter formation with 6 minutes of practice per day for 12 days for one subject has implications for the efficacy of systematic handwriting instruction and the development of a nonword vocabulary in the graphemic lexicon.

CHAPTER I
INTRODUCTION TO THE PROBLEM

Introduction

Legible handwriting is important to academic achievement and to occupational role performance. Students need to take notes, write answers to test questions, copy information, and express ideas in writing. These abilities translate into adult occupational behaviors such as writing a check, making a grocery list, completing an application form, and scribing a telephone message. Although an "age of technology" exists in which computers have revolutionized communication, basic handwriting skills are needed for communication in situations where the use of a computer is impractical (Furner, 1985).

Since handwriting is a basic skill that is required to some degree for all occupations, it is not surprising that handwriting has been studied in diverse fields of education, rehabilitation, psychology, and neurology. In education, teaching paradigms and handwriting proficiency and legibility have been the focus of study (Peck, Askov, & Fairchild, 1980). Through the use of applied behavior analysis, special educators have sought to improve handwriting rate and legibility in children with handicapping conditions (Bijou, Birnbrauer, Kidder, & Tague, 1966; Hopman & Glynn, 1988; Kerr & Lambert, 1982; Sulzer-Azaroff & Mayer, 19860. Retraining and compensatory efforts in the rehabilitation of children and adults have been based upon the development of handwriting ability (Benbow, 1988; Erhardt, 1974; Gesell, 1940; Halverson, 1931; Knickerbocker, 1980; Olsen, 1980), motoric aspects of handwriting (Rosenbloom & Horton, 1971; Wynn-Parry, 1966), and prerequisite skills needed for handwriting (Newman, 1982; Stephens & Pratt, 1981). Dynamic features of handwriting production including the velocity, acceleration, and force of writing movements have been precisely measured in psychophysical studies (Kao et al., 1986b; Teulings & Thomassen, 1983). Neuropsychological and neurophysiological studies have identified brain areas active during handwriting activities in impaired clients (Deecke, Heise, Kornhuber, Lang, & Lang, 1984). Neuropsychological explanations and models of the processes underlying written communication have been derived from the study of handwriting disorders in persons with cortical lesions (Ellis & Young, 1988; Roeltgen, 1985).

Handwriting is a complex skill that involves language, motor, and visual perceptual processes (Ellis & Young, 1988; Roeltgen, 1985). Formal instruction for the development of this skill usually begins in first grade (DeHaven, 1985;

Petty, Petty, & Becking, 1985). Most children make normal progress in handwriting and go on to use writing for communicative purposes. For some children, however, the act of handwriting itself poses serious problems for academic performance.

Two causes for handwriting problems have been suggested by Graham and Miller (1980). Some handwriting problems are due to central nervous system disorders such as cerebral palsy (Bachmann & Law, 1961) or spina bifida (Hancock & Alston, 1986) that interfere with handwriting and other fine motor activities. However, the primary reason posed that some children fail to develop legible handwriting is inadequate instruction (Enstrom, 1966; Graham & Miller, 1980).

Copying tasks constitute a major form of handwriting instruction. Children copy from a chalkboard or overhead transparency and from workbooks and worksheets (Addy & Wylie, 1973). Although a seemingly simple task, copying requires the child to focus his or her eyes on the letter form, visually analyze the components of the letter, recall the relationship of those components, translate the visual image into a motor plan of action, and monitor the movements of the eyes and hand in the reproduction of the letter (Kirk, 1980).

In an extensive review of the literature on handwriting processes, instruction, and intervention, it was found that investigators have not focused upon the effects of the location of the material to be copied. Copying from a chalkboard or from a source at the child's desk is a daily activity throughout a student's schooling. Although copying is a prevalent form of instruction, investigations of this instructional task were few in the literature.

Statement of the Problem

The problem investigated in this study was the effect of stimulus distance on handwriting legibility in children with handwriting problems. The fundamental question related to this problem is to what extent the placement of a handwriting model proximally (near to) or distally (away from) affects handwriting legibility in children who exhibit handwriting difficulties. Specifically, this investigation sought to address the effects, if any, upon 0.5-meter, 3-meter, or 6-meter distances from the stimulus upon the rate of correctly formed letters and the rate of correctly spaced words in samples of second grade children's handwritten copying.

The results of this study can provide school personnel with information that may impact the use of copying tasks routinely required on a daily basis in the classroom. First, the study results provide data on the effect, if any, on handwriting legibility as a result of the stimulus distance from the child. Second, the study addressed the question of stimulus distance upon individual aspects of handwriting legibility: letter formation and word spacing. Findings from this study can be useful to regular classroom teachers, special education teachers, occupational therapists, and other school personnel for curriculum and therapy planning. Finally, the results of this study can be useful to persons from any field who are interested in handwriting research.

Purpose of the Study

The purpose of this study is to investigate the effects of three distances of handwriting stimuli on handwriting legibility of second grade children with handwriting difficulties. Stimuli were placed either 0.5 m, 3 m, or 6 m from the child. These three distances are roughly equivalent to the distance of stimuli when copying from materials placed at the desk or when copying from the chalkboard while sitting in the front row of desks or in the back row of desks in a regular elementary school classroom. Handwriting legibility was judged for correct letter formation and for correct word spacing.

Rationale of the Study

In this section the rationale for the study of the effect of stimulus distance on children's handwriting legibility is discussed. First, handwriting problems are reviewed. Second, handwriting instruction is briefly described. Third, a discussion of copying behavior includes the instructional use of copying tasks and analysis of the visual, attentional, and motor subskills needed for copying and speculations about possible impact of stimulus distance on handwriting performance.

Handwriting Problems

Most children have the visual acuity, oculomotor control, eye-hand coordination, motor planning ability, and attentional capacity to engage in copying and other instructional tasks and to develop adequate handwriting. However, for children who may not have had the readiness activities or who have not benefitted from them as much as their classmates, handwriting skills may not readily develop. Similarly, for the child whose central nervous system maturity is at the lower end of the normal distribution, highly complex activities such as handwriting may be difficult. Some children lack maturity in their ability to attend to classroom tasks and to stay focused upon relevant material. For children with learning, emotional, attentional, or motor deficits, handwriting may be one of many problems encountered in school. For children with any of these problems, handwriting tasks may challenge the limits of their abilities.

Problems with handwriting can impede academic progress and obscure a student's talents and competencies. Handwriting difficulties are common in children with learning disabilities (Belka & Williams, 1979) and have been identified in gifted children (Salend, 1984). An estimated one child per classroom has severe handwriting problems (Cavey, 1987). Problems with handwriting and fine motor skills constitute one of the most common reasons that children are referred to occupational therapists who work in the school system (E. Vizvary, personal communication, October, 1988). Poor handwriting has been cited as the culprit in spelling errors (Johnson, 1984; Strickling, 1973) and in the failure of students to meet minimum standards on ninth-grade aptitude tests of writing proficiency (Kilpatrick, 1983). Pupils with poor handwriting are likely to get lower grades although the content of their work is comparable to that of pupils with good handwriting (Briggs, 1970, 1980; Rondinella, 1963; Markham, 1976; Soloff, 1973). Children identified by teachers as at-risk for developing academic problems were found to have significantly lower scores in efficient handwriting than normal children (Goodgold, 1983).

Handwriting Instruction

Factors for optimal handwriting instruction are important for all children, but especially for those children having handwriting problems or who are at-risk for developing these problems. Graham (1980) suggested that inadequate instruction accounts for the majority of handwriting problems, except for those problems resulting from a neuromotor deficit. Several things may account for the inadequacies in handwriting instruction. Teachers may have been inadequately trained to teach handwriting (Groff, 1962) and may have preferred to teach other subjects (Greenblatt, 1962). In addition, certification agencies may not have required the teachers to have handwriting preparation (King, 1961) and school district curriculums may not have recommended a formal handwriting program for their pupils (Addy & Wylie, 1973; King, 1961; Wolfson, 1962). Handwriting instruction has been conducted typically for the entire class without individualized instruction (Addy & Wylie, 1973). The lack of systematic handwriting evaluations have made it difficult for teachers to identify specific problem areas in handwriting (Graham, 1982). For children referred to special education, emphasis upon mathematics and reading deficits have had priority over handwriting difficulties. These factors have posed potential instructional inadequacies for the child who has had or is at risk for developing handwriting problems.

Analysis of Copying

Every school day, students copy information presented on the chalkboard or at their desks. In elementary school, teachers use copying tasks daily to teach handwriting to first and second grade children. Copying is a complex task requiring visual, attentional, and motor subskills (Petty et al., 1985). These subskills needed for handwriting are discussed.

Visual subskills. Copying from the chalkboard involves complex oculomotor and optical processes. The child needs to have adequate visual acuity so that the material to be copied is seen clearly. Focusing for near vision (near triad) and far vision (stereoscopic depth perception) are involved in the shift of the eyes from the stimulus to the writing paper. To identify the specific letters or words to be copied, the eyes must selectively locate the stimulus to attend to (saccades) and maintain focus upon that stimulus (fixation). Coordinated movements of the eyes (conjugate eye movements) and coordinated movements of the eyes and head (compensatory eye movements) are involved as the eyes and head move to look from stimulus to writing paper.

To be ready for handwriting instruction, the child entering first grade should possess, or be able to quickly develop, a number of readiness skills in visual perception. Children need to be able to differentiate between right and left and sizes and shapes, understand left-to-right progression across a page, and discriminate parts from the whole and the spatial relationships among those parts (DeHaven, 1983; Petty et al., 1985; Lindsey & Beck, 1984).

Attentional subskills. During the process of learning to write, attention is focused upon the act of writing itself and movements are deliberate and laborious (DeHaven, 1983). For successful copying, the child must visually and selectively attend to each letter to be copied, refrain from being distracted as that letter or word is retained in visual memory and translated to a motor pattern, and, finally, the child must focus on the motoric reproduction of the letter on the paper. As motor movements become established and automatic, attention can be directed to refinements of the letter forms and the communicative aspects of handwriting.

Motor subskills. Motor subskills include the ability to maintain head and body postural control necessary for the writing position and tool prehension. Eye-hand coordination must be sufficient for the child to control the movements of the writing tool. Planning of motor movements is required to direct the writing tool in letter formation. Visual-spatial perception must be coordinated with the organization of movements to produce the desired graphic letter representation (Gilfoyle & Hays, 1980).

In summary, copying is a highly complex task, demanding visual acuity and perception, attention to the task, and the ability to organize sequences of motor movements in response to visual stimuli. Intact visual, motor, and attentional abilities are needed for handwriting development.

Copying tasks. Copying tasks are commonly used in handwriting instruction, yet there is a paucity of literature to suggest optimum uses of copying tasks. Copying has been shown to be superior to faded tracing for learning letter formation (Hirsch & Niedermeyer, 1973) and for learning to write shorthand symbols (Askov & Gref, 1975). Improved copying as a result of combined verbal instruction and demonstration (Sovik, 1976) and as a result of motion models versus still models (Sovik, 1979; Wright & Wright, cited in Peck & Askov, 1980) have been shown. Geometric form copying in response to a proximal model was found to be superior to copying from a remote model in a study of 7 and 10 year old children (Sovik, 1979). However, the effects of distance on handwriting performance when copying from material placed at the desk or on a chalkboard have not been investigated. For the child who has handwriting problems or who is at risk for developing these problems, stimulus distance may affect visual, attentional, and motor aspects of handwriting.

Distance of stimulus. The distance of the stimulus is posed by this investigator as a possible factor in copying performance. As the distance from the stimulus increases, the visual, attentional, and motor demands are thought to also increase. For the child at risk for developing handwriting problems, performance could deteriorate at any point in the copying process when the stimulus is distant from the child.

For visual performance, the farther the stimulus is from the child, the longer the interval between seeing the stimulus and writing it. The child may have trouble retaining the visual image of the model as he or she shifts his or her gaze from the chalkboard and paper. The farther the stimulus, the greater the demands on stereoscopic depth perception and the greater the amount of movements and adjustments of the eyes as the eyes adjust from chalkboard to paper and back. It may be taxing for the at-risk child to alternately focus their eyes between stimuli on the desk and chalkboard.

For attention, the farther the stimulus is from the child, the greater the amount and variety of stimuli that the child must screen out in order to attend to the relevant stimulus. It may be difficult for a child with attentional problems to screen out the classroom stimuli that compete with focusing upon a letter on the chalkboard.

For motor performance, with distant stimuli, the child must retain the visual image, make postural adjustments of the eyes and head, and organize the motor movement. The child may become disorganized when composing the movement to match the visual image or when comparing the letter he or she has just copied to the model. It is possible that bringing the stimulus closer to the child could reduce the visual, attentional, and motor demands of the task and make it easier for the at-risk child to copy a handwriting model.

Variables in copying behavior include visual, attentional, and motor variables within the child and teacher, setting, and materials variables within handwriting instruction. It is possible that the distance from the stimulus has little effect on copying performance and other factors need to be considered. The results of this study can offer information to rule out stimulus distance as a factor to consider for optimal handwriting instruction.

In summary, the rationale for the study has been described. Handwriting problems in children were briefly described. Second, handwriting instruction issues were discussed. Finally, handwriting copying tasks were discussed including an analysis of the visual, attentional, and motor aspects of copying, copying tasks, and distance from the stimulus. Definitions used in this investigation are listed next.

Definition of Terms

Allograph refers to the various forms for representing individual letters, i.e., upper case, italic, lower case, etc.

Auditory-language process refers to the analysis of auditory information for reading, speaking, and composing information for writing.

Auditory-language-motor process refers to the analysis of auditory information for language functions expressed through motor acts such as handwriting.

Brain stem is below the cerebral hemispheres and subserves motor, sensory, autonomic, and attentional functions that are reflexive and not voluntary.

Carpal refers to the wrist.

Ciliary muscle attaches to the lens of the eye and when contracting causes a release of lens tension and rounding of the lens for near vision.

Cocontraction refers to simultaneous contraction of two or more muscles.

Cranial nerves are the peripheral nerves of the brain stem that innervate facial and eye muscles.

Cursive writing refers to flowing script where the letters are joined together.

Distal means away from the center of the body.

Dysgraphia refers to an impairment in the ability to write due to a pathological disorder.

Forward flexion refers to movements in the front-to-back plane such as bending the head or trunk down to look at or touch the toes.

Grapheme is the written or printed visible representation of a letter.

Graphomotor is used synonymously with handwriting and refers to the motion pertaining to writing.

Head rotation refers to the side-to-side movement of the head as in responding, "no."

Kinesthetic refers to the sensation of movement, weight, resistance, and position of the body or parts of the body.

Lateral rectus muscle refers to the muscle on the outside of the eyeball that causes the eye to turn to the outside.

Lateral tilt refers to the side-to-side movements of the head as in the movement of the head to respond "maybe." Tilting is also seen in the shoulder, pelvis, or trunk.

Lexicon refers to a conceptualized storehouse of elements of language: phonemic (individual sounds), graphemic (individual letters), grammar, and syntax.

Manuscript writing is synonymous with printing.

Medial rectus muscle refers to the muscle attached to the nose-side of the eyeball and causes the eye to turn in towards the nose.

Metacarpals are the hand bones between the wrist and fingers.

Motor programming refers to the psychoneural activity involved in planning and execution of movements.

Postural adjustments refer to automatic movements to bring the body parts into alignment for an advantageous position to orient to a task.

Premotor cortex is the section of the cerebral cortex that is important for sensory-guided voluntary movements such as writing.

Primary motor cortex is the section of cerebral cortex that is responsible for finely graded movements of the fingers and variations in force required to manipulate objects such as writing tools.

Proprioception refers to the sensations that arise from within the body regarding spatial position and muscular activity or to the sensory receptors that they activate. Proprioception is contrasted to stimuli arising from the environment or the internal organs.

Proximal means towards the center of the body.

Pupillary sphincter is the concentric muscle that causes the pupil to constrict.

Scapulohumeral refers to the shoulderblade (scapula) and upper arm bone (humerus).

Supplementary motor area is the section of the cerebral cortex that has a role in programming of movements such as movements required in handwriting.

Tripod pencil grasp is grasp of the pencil with the index and middle fingers and the thumb.

Vestibular refers to the sensory system that perceives movement of the head and position of the head in relationship to gravity.

Visual language motor process refers to the analysis of visual information for language functions expressed through motor acts such as handwriting.

Delimitations of the Study

This study was delimited by geographical region, subject age and disability, and handwriting variables. The geographical region was restricted to Gainesville, Florida, population 84,200 (Gainesville Chamber of Commerce, personal communication, June 7, 1989) located in Alachua County in north-central Florida. Subjects for the study were 7 and 8 years of age who had completed at least 1 year of manuscript writing instruction prior to the study and who had handwriting difficulties. Excluded from the study were subjects who had neuromotor problems such as cerebral palsy, sensory problems such as blindness or deafness, language disorders such as aphasia, or emotional disorders such as autism. Subjects attended Terwilliger Elementary School and were in regular second grade classes and some also received services in the varying exceptionalities resource room or the program for gifted students (Alachua School District, 1989) or the Chapter I classroom (School Board of Alachua County, 1989). All subjects were male and were right handed for writing. Subjects represented middle and low socioeconomic backgrounds and included minority and nonminority races. The independent variables consisted of three distances of a handwriting copying model from the subject. The sentences to be copied consisted of nonwords. The legibility of handwriting was assessed for letter formation and word spacing and not for letter slant or handwriting speed. Stimuli to be copied were placed on an upright surface directly in front of the child. Copying from a workbook, from stimuli placed on the desk or to one side of the subject was not addressed in this study. Other aspects of copying that were not considered included content, composition, writing to dictation, and spontaneous writing. Visual and attentional aspects of handwriting were addressed, particularly as they related to the motor aspects of handwriting. Visual perceptual processes and language issues related to handwriting were not part of this investigation.

Limitations of the Study

This study included second grade children identified by their teachers as having difficulty with handwriting or second grade children who were in the regular classroom and received services in a varying exceptionalities resource room or in a Chapter I program and therefore the findings should not be considered for other handicapped or for nonhandicapped individuals. In addition, the results cannot be applied to other areas of handwriting. The conditions were administered for children in a regular second grade classroom and therefore may not be appropriate for other grades without replication of the study.

Summary

In summary, the rationale for this investigation stems from several observations. Copying from the chalkboard or from material at the desk is an everyday occurrence in handwriting instruction. Copying from the chalkboard is a complex visual, attentional, and motor task. Some children develop or are at risk for developing handwriting problems and this may be due primarily to handwriting instructional practices. Optimizing copying tasks could enhance handwriting instruction, especially for those children at risk for developing handwriting problems. There is a paucity of information about optimal factors for copying tasks. The distance of the stimulus from the child is posed as one factor that could affect handwriting performance.

In Chapter II literature relevant to this study is reviewed, and in Chapter III the methods for conducting the study are delineated. Chapter IV contains the results of the study and Chapter V includes the implications and conclusions.

CHAPTER II
REVIEW OF THE LITERATURE

Introduction

In Chapter II, a summary and an analysis of the professional literature related to neuropsychological processes for handwriting and to handwriting assessment and instruction are presented. The chapter is divided into four major sections. The first section includes selection criteria for the literature that was reviewed. Section two includes neuropsychological and neurological literature related to motor, visual, and attentional processes for handwriting. In sections two and three educational literature regarding handwriting evaluation and handwriting instruction is reviewed.

Selection of Relevant Literature

An initial step in the review of the literature was that of determining the criteria for the inclusion of the references. All relevant studies completed in the last 10 years (1979-1989) were examined. In addition, any notable researched cited in the literature earlier than the 1979-1989 time period was also considered. Professional literature concerning neuropsychological processes for handwriting and handwriting evaluation and instruction was examined by using the following criteria for inclusion in the review:

1. The subjects and the settings in which the experimentation took place had to be thoroughly described.
2. The treatment conditions and experimental procedures were detailed enough to permit replication.
3. The experimental design and data analysis procedures were presented without significant losses of information.
4. The interpretations of the experimenter had to be consistent with the results displayed.

In order to conduct a comprehensive review of the literature relating to handwriting, the following sources of literature review were consulted: Dissertation Abstracts International, Educational Resources Information Clearinghouse (ERIC), Psychological Abstracts, Current Index to Journals in Education (CIJE), and Index Medicus.

Literature on the neuromotor aspects of handwriting was reviewed in journals including Annals of New York Academy of Sciences, Annual Review of Neuroscience, Brain, Brain Research, Experimental Brain Research, Journal of Neurophysiology, and Human Neurobiology. Psychophysical analyses of handwriting were reviewed in journals including

Acta Psychologica, *Biological Cybernetics*, *Cybernetics*, *Ergonomics*, and *Visible Language*. Handwriting grip and posture were reviewed in the *American Journal of Occupational Therapy*, *Developmental Medicine and Child Neurology*, *Educational Review*, and *Archives of Physical Medicine and Rehabilitation*.

Literature on handwriting assessment was reviewed in the *American Educational Research Journal*, *Educational Research*, *Educational Review*, *Journal of Educational Research*, and the *Journal of School Psychology*. Handwriting assessment manuals were examined for validity and reliability test development data.

Handwriting instruction was reviewed in educational journals. Since single subject research design was used in the study, the literature review of handwriting intervention included studies in which single subject design was used. Journal sources for these studies included *Educational Psychology*, *Education and Treatment of Children*, *Elementary English*, *Journal of Applied Behavior Analysis*, *Journal of Learning Disabilities*, *Learning Disability Quarterly*, *Progress in Behavior Modification*, and *Pointer*.

References initially selected were located through the library at the University of Florida, through the interlibrary loan system, or through other professionals in the field. Descriptors used in this literature search included handwriting, penmanship, writing, dysgraphia, agraphia, written expression, and combinations of these terms with evaluation, instruction, intervention, learning disabilities, rehabilitation, research, and processes.

The references that were selected were critically reviewed and those that described empirical investigations were chosen based on the investigator's judgment that the references presented a clear description of subject selection, methodology, and results. Professional literature other than empirical investigations were also included if, in the author's judgment, the information that was included provided a valuable contribution to the knowledge base about or an understanding of the motor aspects of handwriting and handwriting evaluation and intervention.

Handwriting as a Neuropsychological Process

The refined use of distal musculature for tool use and speaking is distinctly human. One form of tool use, handwriting, is a visible form of language characterized by the ability to use brushes, crayons, sticks, pencils, pens, markers, and other writing tools to form graphic representations of thoughts and concepts. Such fine visual-motor skill is not explicable in terms of the musculoskeletal system since humans and old world monkeys have very similar hands (Rothwell, 1987). In addition, the organism must be oriented to and attentive during handwriting tasks. The visual and language abilities to understand and use graphic symbols to represent concepts and ideas are expressed through handwriting. Neural control systems account for the refined movements in handwriting and for associated attentional, visual, and language processes.

In this section, handwriting is reviewed in five parts. In part one, a neuropsychological model for the handwriting process is described. In part two, motor aspects of handwriting will include three subsections: (a) cortical substrates of graphomotor skills identified from literature on human and monkey studies of motor cortices, (b) psychophysical analysis of handwriting features, and (c) the ergonomics of grip and posture. In part three, visual aspects of handwriting will be analyzed. In part four, attentional mechanisms important for graphomotor functions will be reviewed. Finally, in part five, an observational analysis of handwriting posture in normal first grade children will be summarized. While the literature reviewed does not usually address handwriting in children, it is relevant for considering neuropsychological processes involved in handwriting. In addition, lesion studies related to handwriting have been conducted with adults and this provides background information for considering neuropsychological processes required in children's handwriting.

Neuropsychological Model of Handwriting

In neuropsychological models, various "systems" or "components" are posed that underlie language functions (Ellis & Young, 1988; Margolin, 1984; Roeltgen, 1985). Such models have been used to explain the ability or inability to speak, spell, or write regular, irregular, and nonwords in persons suffering from aphasia, alexia, or agraphia. A neuropsychological model (Figure 1) for graphomotor ability (handwriting) is proposed by the investigator and includes visual, auditory, language, and motor systems. The model is adapted from Roeltgen's (1985, p. 80) model for writing and oral spelling and Ellis and Young's (1988, pp. 175, 181) functional model for spelling. With the explanation of the model, reference will be made to copying as a graphomotor skill.

In this model, the visual system receives and analyzes individual elements of the visual stimulus to be copied. Spelling of the word can occur through two processes: the graphemic lexicon or the phonological lexicon and phoneme-grapheme conversion. The graphemic lexicon stores visual word images and spellings of words used in writing. This system uses a "whole word retrieval process" (Roeltgen, 1985, p. 81). When a word is to be written, this lexicon releases a series of graphemes in a prescribed sequence and this sequence of graphemes can be expressed in writing, typing, or oral spelling (Ellis & Young, 1988). This system

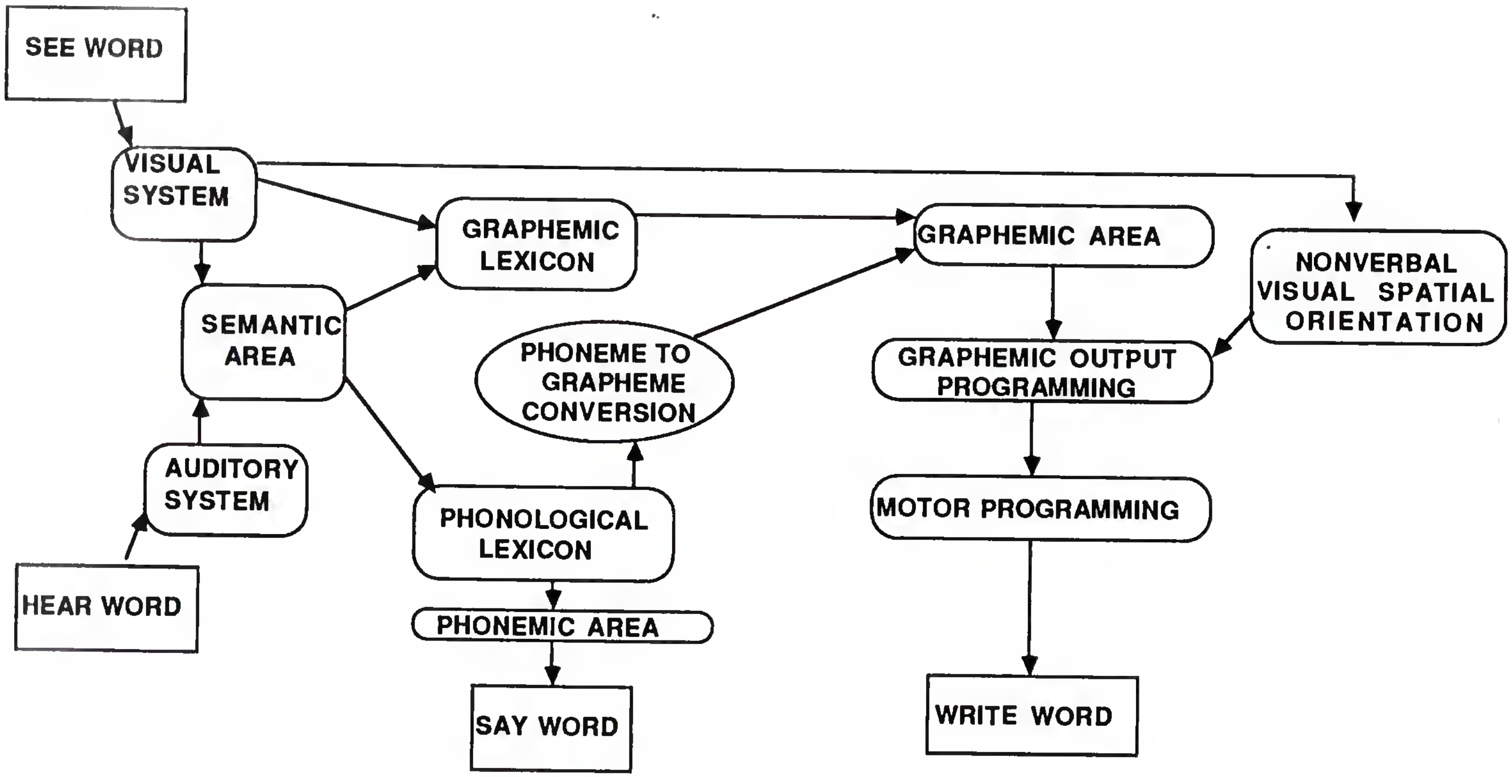


Figure 1. Neuropsychological model for graphomotor skills.

is useful for spelling irregular words that cannot be spelled by matching the sound directly to the letter such as "comb," "knife," and "phone." Through the learning process, this system also stores regular words, such as "animal" where the sound and the letters in the word have one-to-one correspondence. Persons with lesions in the dominant parietal lobe may show deficits in the graphemic lexicon and have difficulty spelling irregular words but can spell regular words due to the preserved abilities of the phonological system and phoneme-grapheme conversion.

In the phoneme-grapheme conversion system, words are broken down into individual phonemes (sounds) and converted to letters, the visual representations of the sounds. Thus, words that are heard can be converted into graphemes for writing. In the process of learning to spell words, children use the phoneme-grapheme conversion system to assemble words from individual sounds, or phonemes. As the spelling vocabulary increases, spellings are increasingly stored in the graphemic lexicon, bypassing the phoneme-grapheme conversion system (Ellis & Young, 1988). The phoneme-grapheme system remains useful for spelling pronounceable nonwords such as "gebit" or for devising the spelling for unfamiliar regular words. With a lesion to the dominant parietal lobe, persons may experience deficits in the phonological system and phoneme-grapheme conversion. They have difficulty spelling nonwords but are able to spell familiar regular and irregular words due to the storehouse of learned words in the graphemic lexicon (Roeltgen, 1985).

For copying, spellings of the words in the stimulus to be copied can be retrieved from the graphemic lexicon or can be devised through the phonological lexicon and phoneme-grapheme conversion. The semantic system provides meaning to the words being copied (Ellis & Young, 1988).

Output of the written word occurs through the grapheme system (Ellis & Young, 1988). The grapheme system is thought to subserve motor movements for writing, whether it be handwriting, typing, assembling plastic letters, or operating a Morse code instrument. A grapheme is a conceptual form of a letter expressed in writing or speaking (Ellis, 1979, 1982). Presumably, visuokinetic motor engrams for graphemes are stored, retrieved, and combined to formulate writing in the grapheme system. Patients with apraxic agraphia can spell orally but exhibit illegible writing response to dictated material. Thus, they know how to select letters in spelling a word but are unable to write a word due to damage to their visuokinetic motor engrams. Their writing improves with copying due to intact visuomotor abilities. Neurological lesions in patients with agraphic apraxia involve the dominant parietal lobe (Roeltgen, 1985).

The graphemic output programming system (Roeltgen, 1985) corresponds to Ellis' (1979, 1982; Ellis & Young, 1988) allograph level where a particular grapheme (written letter) is represented by several allographs: upper case, lower case, manuscript, cursive, and so on. For example, allographs for the grapheme "a" include "a," "A," "*a*," and "*A*." The selection of the desired letter shape occurs at this level.

Programming for graphemic output is influenced by nonverbal, visual-spatial orientation abilities (Roeltgen, 1985). Each letter is written as a series of circular, horizontal, vertical, and diagonal strokes. Individual strokes are thought to comprise the fundamental unit of letter formation and each letter is programmed as a sequence and spatial relationship of one or more strokes (Margolin & Wing, 1983). Patients with spatial agraphia who make errors in single strokes are unable to write on a straight horizontal line, leave blank spaces between graphemes, have problems copying, and tend to repeat the same strokes. Abilities to spell orally and to pronounce words that are spelled indicate intact language areas. The nondominant parietal lobe has been identified as the lesion site in patients with spatial agraphia (Roeltgen, 1985).

Finally, "motor programming" (Roeltgen, 1985) or the "graphic motor patterns" (Ellis & Young, 1988) involve the selection of muscles, timing of movements, and neuromuscular coordination for graphic production. The sequence of the strokes required to create letter forms is formulated here.

Such programming is thought to occur in area 4, the primary motor cortex (Roeltgen, 1985).

Parallel to the visual-language-motor process just described for seeing and then writing a word is the auditory-language-motor process for hearing and then writing a word. In the auditory-language-motor process, the auditory system analyzes the acoustic elements of the sounds. The phonological lexicon stores auditory word engrams and organizes the elements for speaking via the utterance of phonemes to say a word. The semantic system lends meaning to the sounds. These auditory processes can influence graphemic processes through the phonological lexicon and phoneme-grapheme conversion acting on the grapheme system. Through this auditory-language-motor process, dictated words can be spelled and written.

In summary, handwriting is a complex task, requiring combined motoric, visual-spatial, and linguistic efforts. A model of handwriting is useful as a framework for considering the role of various systems in graphomotor performance, especially in clinical populations (Margolin, 1984). As identified in the model, visual, auditory, language, and motor processes culminate in visible expression through the motor act of handwriting.

Motor Aspects of Graphomotor Skills

Motor aspects of graphomotor functions are discussed in four areas. First, cortical substrates for graphomotor skills are reviewed including primary motor cortex, supplementary motor cortex, and premotor cortex. Second, psychophysical studies of features of handwriting are summarized. Third, ergonomic factors including grip and posture are described. Finally, the relationship of these discussions to graphomotor skills is summarized.

Cortical substrates

Findings from animal and human studies of motor cortex functions provide further clarification of the contribution of motor cortices to handwriting and provide a background for study of motor substrates of handwriting in humans. These studies involve direct measurement of cellular activity in the cortex. It is not possible to link findings from cellular research to specific classroom writing activities. However, review of cellular-based research illuminates the complexity of the human skill of handwriting, as considered from a neurocellular level.

Six motor areas have been identified in humans including the primary motor area (MI or area 4), MII at the bottom end of area 4, the supplementary motor area (SMA), the frontal eye fields (area 8), the premotor area (PM or area 6), and Broca's area (frontal operculum) (Rothwell, 1987). Three areas are considered in terms of graphomotor skills: MI, SMA, and PM.

Primary motor cortex (MI). Five functions of the primary motor cortex are briefly discussed: fine finger movements, force of muscle contraction, sensory control of movement, execution of movement, and purposeful reaching. In addition, the primary motor cortex is preferentially involved in control of finely graded movements rather than gross limb movements (Kuypers, 1982).

Primary motor cortex neurons synapse directly on motor neurons in the spinal cord and such direct connections are believed to subserve highly fractionated movements of the fingers (Kuypers, 1982; Muir & Lemon, 1983). Direct spinal motor neuron connections are numerous in monkeys, chimps, and humans and are not seem in marsupials and carnivores with limited fine motor control. Primary motor cortex neurons to the spinal cord develop early during postnatal life and this development coincides with increasing fine motor control of the hand (Kuypers, 1982). Primary motor neurons also determine fine gradations of the force of muscle contraction needed for a given load (Evarts, 1981). In a human with a discrete lesion of the hand region of MI, Freund (1987) observed decreased dexterity and force in the hand and fingers.

Terminations of MI in the spinal cord subserve sensory control (Wiesendanger, 1981). Tight coupling of sensory input and motor output between the brain and spinal cord was found in intracortical microstimulation studies of the individual cells in MI. Primary motor cortex cells that, when stimulated, resulted in movement of a joint also received input from the muscles and joint receptors of that same joint (Rosen & Asanuma, 1972).

The primary motor cortex has been described as the "executive locus for voluntary movements" (Roland, 1985, p. 155). In metabolic mapping studies in humans, MI was consistently active during voluntary movements and was not active when voluntary movements were not being performed (Roland & Friberg, 1985).

In addition to fine finger movements and voluntary motor control, MI is involved in planning and executing purposeful reaching. Georgopoulos (1986, 1987) recorded from single cells in MI and found that 80% of the MI cells that were active in reaching were active when reaching occurred in a "preferred" direction.

Supplementary motor area (SMA). The supplementary motor area is located on the medial surface of area 6, premotor cortex. The SMA exerts its influence bilaterally and is thought to have a role in the programming of movements (Roland, Skinhoj, Larsen, & Endo, 1977; Rothwell, 1987). Five functions include initiation of movements, planning for movements, visually guided movements, visual motor learning, and anticipatory postural preparation for movement.

The role of SMA in the initiation of voluntary movement has been identified in human studies of the bereitschaftspotential (BP) readiness potential averaged from electroencephalograms and compared to electro-myograms (Deecke, 1987). Widespread cortical activity is seen prior to movement and is initially bilateral and then becomes unilateral. This bilateral-to-unilateral shift is thought to reflect SMA, then MI activity (Deecke, Weinberg, & Brickett, 1982; Roland, 1987). For example, BPs in the SMA were recorded 1.2 seconds prior to the onset of EMG activity in bilateral flexion of the fingers; BPs in MI were seen 0.7 seconds prior to the onset of EMG activity (Kristeva & Deecke, 1980).

The role of the SMA in planning movements has also been shown in metabolic mapping studies of humans (Roland, 1987). During the performance of complex actions such as finger-to-thumb sequential movements, the SMA was metabolically active (Roland, 1985).

The SMA has also been found to be active in the early preparation phases for visually guided activities (Deecke, Heise, Kornhuber, Lang, & Lang, 1984). Human subjects drew with a pen the shape of a visually presented stimulus. Subject's eyes were fixated centrally and the stimulus was presented in the left visual field. The subject wrote with the right hand. Before the subject pressed the pen to the paper to initiate the stimulus, BPs were seen in occipital and frontal leads. The SMA BPs stopped 90 milliseconds prior to the pressing down of the pen to initiate the task. In contrast, the occipital BPs stopped 200 milliseconds after the pen was pressed and moved into the correct direction. The authors interpreted this as the SMA having a preparatory, motivational role in initiating the task. The role of the occipital area was to attend to relevant visual stimuli needed to carry out the tracking task.

The possible role of SMA in visual motor learning was shown in a task requiring the subject to visually fixate on a moving target and to track it by writing with a pen (Lang, Lang, Kornhuber, Deecke, & Kornhuber, 1983). In addition to the regular tracking task, a learning task involved inverted mirror tracking. When activity of the SMA and frontolateral convexity during the learning task was compared to activity of these cortical areas during the regular tracking task, "good" learners showed significant increases in cortical activity and "poor" learners showed the same or less cortical activity on the two tasks. Thus, the frontomedial SMA region and the frontolateral convexity appear to be important for visual motor learning.

The role of SMA in anticipatory postural preparation for movements was demonstrated by comparisons of SMA cortical cell activity and EMG recordings in a monkey performing a choice-reaction task (Wiesendanger et al., 1987). Increased SMA neuron activity was observed between the "ready" and "go" signals and this activity corresponded with EMG activity. Thus, in anticipation of the signal to move, the SMA presumably had a role either directly or via MI in tensing of muscles to prepare for movement.

Humans with SMA lesions involving the cingulate cortex had reduced speech, facial expressiveness and spontaneous motor activity (Freund, 1987). Patients had difficulty with bimanual coordination and this persisted after the recovery period whereas unilateral limb movements recovered. Thus, lesions of the SMA resulted in problems with bilateral movement coordination and initiation of movements.

Premotor cortex. The premotor cortex comprises area 6 that lies rostral to MI and on the lateral surface of the frontal lobe. It is continuous with the supplementary motor area that is on the medial surface. In humans, the premotor area is about six times larger than MI and many premotor neurons project to the primary motor area (Rothwell, 1987). Three functions will be described: sensory guided movements, purposive responding, and proximal muscle coordination.

The premotor area is thought to be important for sensory-guided voluntary movements, that is, movements occurring through interaction with the environment versus movements that are centrally programmed such as crawling or walking. The premotor cortex gets abundant visual input and is thought to be especially involved in visually-guided movements (Rothwell, 1987). In studies with humans, Roland and colleagues (Roland, 1987; Roland, Larsen, Lassen, &

Skinhoj, 1980a, 1980b) found that PM was metabolically active during sensory-guided voluntary movements. Neurons in the premotor cortex also responded well to tactile stimuli (Rizzolatti, 1987).

Weinrich, Wise, and Mauritz (1984) identified "set-related neurons" that were active between the onset of a stimulus and the signal to move. Cells were directionally specific and were active if the stimulus was moved in a certain direction in space.

The role of PM in purposive movements was suggested by single cell recordings that showed that PM cells were active during distal arm movements. Cells were more active when the arm movement was directed toward some specific aim and were not as active when the arm was simply moved using the same musculature. The author proposed that the premotor area contains a "vocabulary of motor acts such as reaching, grasping, and holding and that this vocabulary can be addressed by visual and somatosensory stimuli" (Rizzolatti, 1987, p. 180).

The premotor cortex appears to influence proximal as well as distal movements. Lesions of the premotor cortex in humans result in poor bilateral coordination for movements such as pedalling and "windmill" arm motions requiring coordination of proximal musculature (Freund & Hummelsheim, 1985). Distal movements of the two limbs together such as shoe tying and clothes buttoning were unimpaired. However, in patients with lesions that were laterally placed in area 6 just anterior to the hand area of the primary motor cortex, disturbances in distal musculature were seen (Freund, 1987).

Relationship to graphomotor skills. From the foregoing discussion it is reasonable to assume that graphomotor performance involves MI, SMA, and PM. The primary motor area is involved in the fractionation of finger movements and the variations in force required to manipulate a writing tool. As the executive of motor commands, MI is the final link in cortical chains of commands that involve supplementary and premotor areas. All three areas, MI, SMA, and PM are involved in sensory guided movements. Handwriting requires the guiding of movements via visualization of the movement needed to form the grapheme, via visual feedback from the written page and via tactile, proprioceptive and kinesthetic sensations arising from and requisite for the movements as they are produced. All three areas are involved in the purposive nature of handwriting. One writes with the desire and intent to express one's thoughts. Unlike other refined skills, handwriting engenders language in addition to motor and visual systems. Finally, the anticipatory postural preparation for movement provides the writer with body orientation to the task. The writer automatically assumes a writing posture and the stability of the trunk, neck, and shoulder provide adequate support for refined distal movement. In short, MI, SMA, and PM motor cortices are involved in graphomotor performance.

Possible cortical substrates of handwriting have been discussed briefly. Next, the study of psychophysical features of handwriting is reviewed.

Psychophysical features

Through computerized analysis of handwriting performance, several features of handwriting have been observed (Hollerbach, 1981; Hulstijn & van Galen, 1983; Kao et al., 1986a; Teulings, Thomassen, Keuss, van Galen, & Grootveld, 1983; van Galen & Teulings, 1983). A handwriting signal was generated through the use of an electronic pen on ordinary paper that covers an xy (horizontal-vertical) digitizer. Pen tip position registered on the xy coordinates from a fixed point and was sampled across time with a frequency of 200 per second and an accuracy of 0.2 mm (Teulings & Thomassen, 1983). Velocity, acceleration, and form features of handwriting (Teulings & Thomassen, 1983; van Galen & Teulings, 1983), and reaction time and movement time were monitored (Hulstije & van Galen, 1983).

Velocity was measured horizontally, vertically, or in combination (absolute velocity) to give an indication of speed of responding. Normally, in smooth writing, the absolute speed within a word was seldom close to zero for more than 30 milliseconds. The time needed to draw a certain pattern seemed relatively independent of the total length of the pattern that was proportional to its size. For example, a 16-fold increase in writing size resulted in an increase in time by 1.6 (Teulings & Thomassen, 1983).

Acceleration was measured in terms of change in x and y velocity of the pen per unit of time. The acceleration indicated that a force was applied to the pen. The net force equaled the sum of the muscle force and friction forces of the pen tip and hand. Acceleration was considered as the net force pattern produced by the muscle since force exceeded friction. The acceleration pattern looked repetitive although writing contained different letters. This was because various letters were produced by only tiny variations in duration and amplitude of individual xy phases (Teulings & Thomassen, 1983).

Models of handwriting were generated through research on feature analysis of handwriting. In one model, a three-stage process was proposed including (a) retrieval of an abstract motor program from long-term memory; (b) parameter setting of size, accuracy, and speed; and (c) translation of the program and parameters into a neuromuscular response (van Galen & Teulings, 1983). Neurological substrates for these processes were not proposed.

Ergonomic features of grip and posture

Therapists, physicians, educators, and others concerned with early childhood development and with the development of hand skills have studied the motoric aspects of handwriting.

Halverson (1931) and Gesell (1940) used cinema analysis to study the developmental progression of object manipulation in normal children.

Focusing upon finger grasp, Wynn-Parry (1966) labeled the "dynamic tripod" grasp of writing tools that included the thumb, index, and middle fingers functioning together to perform smooth writing movements. This tripod posture was further delineated by Rosenbloom and Horton (1971) into two stages. First, the static tripod posture was used but the fingers remained relatively silent while the wrist moved the hand to write. In the second stage, the dynamic tripod developed in which the fingers moved from the knuckles to produce coordinated pencil movements. Subsequently, Erhardt (1974) identified a developmental progression of grasp for handwriting: (a) fisted grasp at age 1; (b) grasp with all the fingers at age 2 to 3 years; (c) stiff-fingered, static tripod grasp at 3 1/2 to 4 years; and (d) mature, dynamic, tripod posture at 4 1/2 to 6 years.

In a study of normal adults (Kamakura, Matsuo, Ishii, Mitsuboshi, & Miura, 1980), subjects grasped inked objects and the hand was then photographed to show the areas of the hand involved in static prehension of 98 objects. Subjects used the tripod grip to grasp a pencil using

> [a] the radial aspect approximately at the level of the distal interphalangeal joint of the middle finger; [b] the pulp of the index finger; and [c] the pulp of the thumb . . . and when a stick is longer, the radial aspect of the

> metacarpophalangeal joint of the index finger makes contact with it. (p. 441)

Trombly and Cole (1979) used electromyography to determine the involvement of four hand muscles in 16 activities. They found that the extensor digitorum, dorsal interosseus 1, abductor pollicis brevis, and flexor digitorum profundus were about equally involved in the upstroke and downstroke of a pencil but that there were individual variabilities in joint motion among the 15 subjects.

Ziviani (1983) used photographic analyses to study the qualitative changes in dynamic tripod grip between ages 7 and 14. She identified the following variables: degree of flexion of the index finger, degree of forearm pronation/supination, fingers used, and opposition. In a subsequent study, Ziviani and Elkins (1986) found that the type of grip did not influence the speed and legibility of writing. However, they noted that the dynamic application (i.e., the use) of the grip may be more pertinent to writing performance than the type of static grip.

Therapists who have worked with handicapped children have developed evaluations of handwriting that focus upon the motor process of handwriting versus the analysis of the written handwriting product (Goodgold, 1983; Ziviani & Elkins, 1984). The Handwriting Movement Rating Scale was developed to assess the quality of handwriting movements in prekindergarten and kindergarten children (Goodgold, 1983). This assessment included ratings of grip, posture, upper extremity muscle coordination, and sequence of movements (fluency/speed).

Upper extremity strength and dexterity have been determined to be needed for handwriting. Individuals with muscle weakness have received therapy for improving strength and coordination as a basis for facilitating function in various upper extremity skills (Stephens & Pratt, 1989). However, research on the effects of such therapy specifically on handwriting has been limited to one study. In Hong Kong, Kao (1973) examined the effects of hand and finger exercises on tracing in normal adults and concluded that these exercises could enhance precise visual motor control for tracing.

Motorically, the novice handwriter should present with adequate muscle tone and coordination of the trunk, shoulder, and hip girdles and upper and lower extremities to assume and maintain writing postures of the body and hand (Stephens & Pratt, 1989). Adequate upper extremity function depends upon trunk and scapulohumeral stability. In order for the hand to function, the trunk must maintain an upright position so that the arms are not used to support the body. The scapula must be stable upon the upper thorax with the humerus well articulated into the shoulder joint. Hand grasp must be mature for adequate grip of the pencil and forearm supination must be well developed to allow fluid movement of the hand across the page (Ziviani, 1983). In addition, experienced eye-hand coordination is required for the child to manipulate the pencil and reproduce geometric shapes that are the precursors to letter forms (Petty et al., 1985; DeHaven, 1983).

In order to establish the motor plan of movements needed for future encounters with a given letter, the child must be able to integrate the visual image of the letter with muscle kinesthetic and proprioceptive sensations (Ayres, 1985). As the hand moves to write a letter, and as the eyes move to focus on relevant features of the letter, kinesthetic and proprioceptive sensations are produced in the hand muscles and eye muscles. These sensations are characteristics of the eye and hand movements needed to form the letter and are matched to the visual image of the letter. Through this process, the nervous system establishes motor patterns for each letter.

In this section, aspects of grip and posture were described. In the next section, visual aspects of handwriting copying tasks are discussed.

Visual Aspects of Graphomotor Skills

Visual aspects of graphomotor skills include acuity, eye movements, and depth perception. Each of these visual aspects will be discussed.

Visually, the child needs to be able to be free of refractive errors so that the information on the chalkboard is seen clearly. Kindergarten screening for visual deficits is assumed to have identified those children needing refractive examination. During a copying task, the eyes must alternately adjust for near point focus as required to view the paper and for far focus as required to view the chalkboard. Once the chalkboard or paper is viewed, the eyes move to seek out the relevant stimulus, focus on that stimulus, and move in coordination with the head. These oculomotor functions are accomplished through five types of eye movements: the "near triad," conjugate eye movements, saccades, fixation, and compensatory movements.

For near point vision, three eye movements, the "near triad" occur: convergence, lens rounding, and pupillary constriction (Kuffler, Nicholls, & Martin, 1984). The two eyes converge to align the eyes with a near object and this results from cocontraction of the medial rectus muscles of the eyes. Rounding of the lens increases its optical power. Contraction of the ciliary muscles results in relaxation of tension, and thus rounding, of the lens. Constriction of the pupil improves vision through limiting the entrance of stray light. Pupillary constriction results from contraction of the pupillary sphincter. For far vision, the reverse of the near triad occurs.

In order to locate the relevant stimulus on the paper or chalkboard, four eye movements are involved: conjugate, fixation, saccades, and compensatory (Kuffler, Nicholls, & Martin, 1984). Conjugate eye movements provide movements of the eyes in the same direction. For example, to look to one side, the medial rectus of one eye contracts synchronously with the lateral rectus of the other eye. This movement involves the occipital lobe, frontal lobe, paramedian pontine reticular formulation center for lateral gaze in the brainstem pons and cranial nerves III and IV.

Saccadic eye movements refer to voluntary movements of the eyes in which the eyes flick rapidly from one point of fixation to another as when reading. These movements involve the frontal lobe and the brain stem.

Fixation on a visual target is accomplished and maintained through foveation or moving the eyes to locate the target on the foveas, smooth pursuit of the target as it moves so as to maintain fixation and near triad to maintain fixation as the target nears. Fixation involves the occipital lobe and the brain stem.

Compensatory movements of the eyes occur as the head moves. So that visual fixation is maintained, the eyes move in an equal and opposite direction to the head. Compensatory movements involve the vestibular system and cranial nerves to the eyes muscles.

These five types of eye movements are involved in copying from the chalkboard. For close work, the near triad allows the child to focus clearly on the paper. Conjugate movements occur as the child looks up to the chalkboard and across the line of words written there. Saccadic movements occur as the child focuses on a specific letter and then another until the desired letter is located. Once the letter is located, the eyes fixate on the letter while the visual information is being processed. Finally, compensatory eye movements have been observed as the child begins to turn the head to the paper but the eyes linger on the chalkboard a moment longer after head rotation is initiated.

Stereoscopic depth perception (Barlow & Mollon, 1982; Crawford, 1986) is involved in the copying task as the child focuses from desk to chalkboard. When the child looks directly at a letter on a page, the letter is projected onto the fovea of each retina, the foveas being the points of sharpest vision. These points are in corresponding locations on the two retina, thus the two images formed by the two eyes are perceived as fused into one image. As the child looks to the chalkboard, disparate points are stimulated on each retina and some objects in front of the child will appear closer than others. For example, if the child is looking straight ahead with the eyes focused on a letter on the chalkboard, the letter will stimulate corresponding points on the two retina. However, the teacher standing in front of the chalkboard, the children in the desks in front of the child, the bulletin board to the side of the chalkboard will all stimulate different retinal points. Depth perception occurs through the resolution of stimulation of the disparate retinal points and this resolution is brought about by computational aspects of visual processing in the visual cortex.

To see a word and then write it, the brain must attend to the word to be written and not attend to other stimuli in the environment. Memory for what is to be copied must be retained during lexical, semantic, and graphemic processes. Attention to the motor movements are required for graphomotor responses. Neurological mechanisms underlying arousal, attention, and intention will be discussed next.

Attentional Mechanisms for Graphomotor Skills

The role of the brain stem arousal system, the frontal lobes and the inferior parietal lobule will be described briefly. In the brain stem, the midbrain reticular formation (MRF) receives excitation by visual, auditory, and somatosensory sensory systems. The MRF, in turn, has an excitatory input to cortical areas where sensory information is interpreted and processed. The MRF provides arousal of the cortex through the inhibition of the nucleus reticularis, an inhibitor of the flow of sensory input from the thalamus to the cortex (Heilman, Watson, & Valenstein, 1985).

Attentional mechanisms mediated by the inferior parietal lobule have been investigated in recent years in single cell recordings in awake monkeys (Heilman, Watson, & Valenstein, 1985). Cells in this lobule are most active when stimuli are presented that are important to the animal and not active during presentations of insignificant stimuli. Several types of cells have been identified and were named for the function during which they were very active. Projection cells were active when the limb reached for or the hand manipulated a significant stimulus such as food. Visual fixation neurons were active when the distance of the stimulus was within arm's reach, the stimulus was biologically significant or when the eyes were directed towards a certain part of the visual field. Visual tracking neurons were active during visual pursuit of a moving object in a given direction within arm's reach. Similarly, saccade cells were active during saccadic eye movements to visually explore biologically significant stimuli. The inferior parietal lobule is thought to be important for visual attention to stimuli that are important to the organism.

Aside from the motor and language functions of the frontal lobes, these lobes have additional roles in attention, intention, and arousal (Damasio, 1985). Frontal lobe functions have been determined through study of persons with lesions affecting the frontal lobes and from animal experiments.

The frontal lobes help to focus attention on the task at hand. The frontal eye fields located rostral to the frontal motor areas have been cited as the locus of attentional mechanisms. Individuals with lesions to these areas have difficulty with selective attention and lose the ability to orient to stimuli in contralateral space (Damasio, Damasio, & Chui, 1980; Heilman & Valenstein, 1972). Some persons are unable to orient to stimuli that are relevant and, instead, attend to irrelevant stimuli. Organized movements of the eyes to scan a visual stimulus and increasingly fixate on important aspects of the stimulus are impaired and the eyes move in random fashion (Luria, 1973).

The dorsolateral frontal cortex is thought to be important for intention, a plan of action based upon information inherent in a situation. This function of the frontal lobe enables one to notice cues in the environment or within one's self as to what needs to be done next. One's motives or intentions are tempered by social and personal constraints. Persons with lesions in the dorsolateral frontal cortex are unable to develop strategies and plans and lack the ability to benefit from feedback. Problems with disorganization, decision-making, taking responsibility, and observing social rules are seen (Damasio, 1985).

When a child copies information from a chalkboard in school, the eyes must engage the relevant stimuli on the chalkboard, the sights and sounds of neighboring students must be ignored, the child must develop a plan to complete the task and be able to persevere until finished. These behaviors require the attentional mechanisms described above.

In summary, writing movement is an end product that reflects linguistic, visual, motor, and attentional programming functions of the brain. Graphic motor output is possible when linguistic components are converted to motor output and nonverbal, visual spatial orientation contributes to the programming for graphemic motor output in the context of attention to the given task. Discussed next are observations of these graphomotor processes in normal first grade children learning to write.

Qualitative Investigation of Copying Behavior

In a qualitative investigation of 20 first grade children in a normal first grade classroom, the following motor, visual, and attentional subtasks were observed to be involved in copying from the chalkboard (Walker, 1988). The typical head posture for handwriting included the head bent in slight forward flexion, tilted slightly towards the right to bring the nose slightly in the direction of the right shoulder. This posture enabled the child to bring the eyes to the paper to see what was being written. Shoulders were generally level and not tilted. Upper arms were held in elbow and shoulder flexion to orient to the task. The nonwriting hand stabilized the paper. The trunk was held erect with slight forward flexion of the trunk to bring the body against the table edge. The pelvis was level and lateral tilting was not observed. The thighs and lower legs were held in relaxed position with both feet on the floor. Some children crossed their legs at the ankles but none of them crossed their legs at the knees. The mature three-finger tripod pencil grasp (Ziviani, 1983) was predominantly used.

The children used their eyes to monitor and guide the hand, but the eyes were directed to the letter being produced on the paper and not on the hand itself (Walker, 1988). The children were able to integrate the kinesthetic and proprioceptive sensations being produced by the movement with the visual image of what was being produced on the paper and to use this integration in eye-hand coordination. Most children copied only one letter at a time. To look for the next letter to be copied, the child rotated his or her to midline and held the head steady while looking at the chalkboard to locate and focus upon the next letter to be written. Having found the letter, they made postural adjustments to bring the head, eyes, and hands again into the writing position. Children concentrated on the task and their demeanor was one of absorption with the task.

In summary, copying from the chalkboard is a highly complex task, demanding visual acuity and perception, attention to the task, and ability to organize sequences of motor movements in response to visual stimuli. Intact visual, motor, and attentional abilities are needed for handwriting development.

Handwriting Evaluation

Several assessments of handwriting products exist in which a sample of the writer's handwriting is rated by an examiner (Barbe, Lucas, Hackney, Brain, & Wasylyk, 1984; Bezzi, 1962; Freeman, 1959; Hammill & Larson, 1983; Phelps, Stempel, & Speck, 1985; Stott, Moyes, & Henderson, 1985; Ziviani & Elkins, 1984). However, the psychometric properties of handwriting measures have been questioned for flaws in validity, reliability, and usability (Graham, 1986a, 1986b).

Validity

The validity of handwriting assessment is affected by "ambiguity of the criterion variables" (Graham, 1986a, p. 64) in which definitions of terms such as "legibility," "well-proportioned," or "properly formed" are imprecise. An individual's handwriting varies from day to day and "physiological, experiential, motivation, and psychological factors" (Graham, 1986a, p. 65) have been determined to influence handwriting performance. Thus, it may be invalid to assume that performance on a single handwriting sample is representative of the individual's capacity. The nature of the assignment can also influence handwriting performance since persons perform differently under different performance expectations. The person who scores the handwriting sample can introduce variability by imprecise application of a set of criteria, by fatigue or by knowledge of the intended consequences to the subject of the scoring results. Although handwriting scales have adequate face validity, the population of writing samples are not comprehensive for the range of performance for a group of children. Lack of concurrent validity study is due to the paucity of handwriting measures and to the standardization limitations of the available instruments.

Of the handwriting instruments reviewed, the Evaluation of Handwriting Performance (EHP) (Ziviani & Elkins, 1984) included content, criterion-related, and construct validity investigations. For content validity, a specification table was used to judge that EHP subtests were representative of handwriting components in research reported in the literature, including formation, spacing, alignment, size, and speed. Each test component included items for letters and symbols. For criterion validity, subjects' scores on letter and symbol test items were thought to be measures of the same handwriting criteria and these scores were correlated. Some agreement was found on measures of the same criteria: .72 for formation, .52 for spacing, .67 for alignment, and .76 for size. Construct validity was investigated through factor analysis. Of the total variance, 70% was accounted for by four factors: formation, size, spacing, and alignment. Other tests reviewed did not include validity investigations.

Reliability

For the tests reviewed, reliability data were scarce, yet, when available, were generally acceptable. For the EHP (Ziviani & Elkins, 1984) interrater reliability correlations for formation, spacing, alignment, and size were, respectively, .76, .91, .88, .97, and .95. Test-retest reliability correlations were .79 for formation, .51 for spacing, .48 for alignment, .61 for size, and .93 for speed. Test-retest correlations for the grade 3 subjects were lower than retest correlations than the grade 6 subjects and the investigators interpreted this as being due to a greater variability and range of performance of younger children as compared to older children.

Test-retest reliability coefficients were reported at .81 to .90 on the Test of Written Language (TOWL) (Hammill & larson, 1983). Interrater reliability of the TOWL was established by comparing 15 teacher's ratings to the average rating. If the individual teacher's rating was within one point of the average rating, the teacher was assumed to be in agreement. The percentage of agreement was .76.

Reliability of .38 to .87 has been reported for the Freeman Scales (Feldt, 1962). Zaner-Bloser (Barbe et al., 1984) reliability is reported at .74 to .98. The average scorer agreement in the ratings of two judges on the Children's Handwriting Evaluation Scale (CHES) (Phelps et al., 1985) ranged from .88 to .95 and reliability ratings for a single rater ranged from .64 to .82. Interrater reliability for the Diagnosis and Remediation of Handwriting Problems (DRHP) (Stott et al., 1988) was assessed by comparing the ratings of two assistants to the primary author of the test and reported at .56 and .66.

Usability

Although the results of existing handwriting assessments provide general information about handwriting performance, they provide limited diagnostic information as to the specific handwriting problems. A handwriting sample is rated in toto on a 0-10 scale (Hammill & Larsen, 1983; Phelps et al., 1985) or according to criteria lists (Ziviani & Elkins, 1984; Stott et al., 1986). Criteria for letter formation is limited either to manuscript writing (Ziviani & Elkins, 1984), to cursive writing (Hammill & Larsen, 1983) or contains overlapping categories (Stott et al., 1986). Norm-referenced information is lacking except for one test developed in the United States where handwriting is scored as part of an overall language evaluation (Hammill & Larsen, 1983) and one test developed in Australia (Ziviani & Elkins, 1984) which has limited use for non-Australian children. Existing handwriting scales provide cursory evaluation of handwriting performance but are insufficient for planning handwriting intervention.

In using existing instruments to assess handwriting of children with learning disabilities, the investigator assessed the usability of three instruments: the TOWL (Hammill & Larsen, 1983), the DRHP (Stott et al., 1985), and the Evaluation of Handwriting Performance (EHP) (Ziviani & Elkins, 1984). An advantage of the TOWL is that it was standardized on children 7 to 18 years of age in the United States. In addition, normative data are provided for children in the United States. The TOWL (Hammill & Larsen, 1983) and the DHRP handwriting samples were limited to spontaneous writing in response to pictures and, thus, handwriting for copying or in response to dictation could not be measured. The DHRP was developed in England as a comprehensive, criterion-referenced assessment of handwriting that could be used with children and adults. For assessing letter formation, the DHRP was useful because Part I of the instrument contained 14 categories of "faults" that could occur with handwriting and representative problems were depicted. However, the categories were not mutually exclusive and it was difficult to separate letter formation "faults" in Part I on the instrument from problems in Part II of the instrument. For example, one fault in Part I was that the "letter has an unusual feature that interferes with reading" (Stott et al., 1986, p. 16), yet in Part II there was a rating for "random letter distortion" that was scored 0 to 3. As noted in Daniels' (1988) review, the clinical usefulness of the DHRP is limited by the lack of guidelines for score interpretation.

Handwriting samples on the EHP included drawing geometric forms, writing words to dictation, copying a sentence, and writing a phrase repeatedly to assess writing speed. Scoring methodologies for word alignment, spacing, and size were readily usable in the EHP. However, the evaluation of letter formation was limited to manuscript writing of children in grades 1 through 3. The EHP was standardized on Australian children. Furthermore, samples were written on unlined paper, which may not be appropriate for use in the United States where children traditionally are not expected to write on unlined paper. However, scoring methods for letter formation and word spacing, alignment, and size were well-described.

In this section, handwriting evaluation has been discussed. Problems with validity, reliability, and usability were reviewed. Next, methodologies for handwriting instruction will be described.

Handwriting Instruction

In this section, general information on handwriting instruction will be reviewed. Second, single subject research studies of handwriting instruction will be summarized.

Background Information

Background information on handwriting from sundry sources will be considered next. The following aspects of handwriting instruction will be briefly described: developmental aspects; modeling; manuscript versus cursive; Palmer, Zaner-Bloser, and D'Nealian methods; the letter as the basic unit of handwriting; handwriting legibility; handwriting rate; and computer versus handwriting modes of output.

Developmental aspects

Manuscript handwriting instruction begins in first grade with cursive introduced in the second half of the second grade (Mercer, 1987). Formation of letters are emphasized in the first years, and after grade 3 composition and writing as a form of communication are stressed. By the end of the first three years of school, most children have developed handwriting that is legible and have begun to exhibit individual styles of handwriting.

During the first year in school, the child learns to write all 26 alphabet letters, lower and upper case, and the 9 numerals. In grade 2, the child refines the letter formations and begins cursive writing in the second semester of that year. By the end of the third year in school, the child has mastered 26 upper and lower case manuscript and cursive letters for a total of 104 letter forms and uses handwriting for creative writing and in practical classroom situations (DeHaven, 1983).

By school age, the child is able to adopt the typical position for writing with the pencil held with a tripod grasp, 1 inch above the tip with the eraser end pointed towards the right shoulder for right-handed persons and the left shoulder for left-handed persons. The paper is positioned straight for manuscript writing and tilted with the lower left corner (or for left handers, the lower right corner) towards the center of the body (Petty et al., 1985).

Studies of the developmental mastery of letter formation in normal children have inconsistent results in terms of the order in which letters are mastered. In a case study of a 2 1/2 year old girl, McCarthy (1977) observed that circular letters (o, c, q) were acquired first, straight line letters (l, t, i) next, letters with loops (b, p, r) next, and letters with acute angles and diagonal lines (m, n, z) last). Coleman (1970) found that the first letters 5 year olds learn to copy were l, r, f, t, and x, and the last letters they learned to copy were w, d, z, y, and q. Lewis and Lewis (1964) ranked the letters l, v, c, x, and h as the easiest letters and q, g, p, y, and j as the most difficult letters for first graders to write. Instructional and measurement variables may have been significant factors in the results of these studies.

Modeling

Modeling of the letters can affect outcomes of handwriting instruction. For a child to be able to write a letter, the child first needs a visible model of the letter. Next, the child can produce the letter from a model "written" in the air. Third, verbal descriptions of the letter can guide the child in writing. Finally, the child can produce the letter by hearing just its name (McCarthy, 1977). Motion models of how to move to write the letters were found to be more effective than still letters in children's acquisition of letter forms (Wright & Wright, cited in Peck, Askov, & Fairchild, 1980; Sovik, 1979). In a study of copying abilities of 21 7-10 year old children, Sovik (1979) found that children performed better copying from a model placed 2 feet away than one placed 12 feet away.

Manuscript versus cursive

Educators have mixed opinions as to whether manuscript or cursive writing is preferred for early instruction. Proponents of manuscript (Barbe, Milone, & Wasylyk, 1983; Graham & Miller, 1980) questioned the need to teach two writing forms, manuscript and cursive, when manuscript can be just as fast and legible as cursive. Movements for manuscript writing are thought to be simpler and easier to learn than cursive. Barbe and colleagues (1983) analyzed the writing of the word "was" and found 12 strokes, 11 joinings, 3 letter joinings, and 6 retraces for cursive writing as compared to 7 strokes, 4 stroke joinings, and no letter joinings and retracings for manuscript writing. They concluded that cursive was four times as difficult as manuscript writing. Similarly, Jackson (1971) found that manuscript writing was significantly faster than cursive for intermediate grade children. Contrary to this, Suen (1983) found cursive to be faster than manuscript or block printing. Manuscript writing is needed throughout life for its legibility as required for completing application and other forms. The independence of letters in manuscript is also believed to promote spelling (Hagin, 1983).

Manuscript letters more closely resemble typeset letters than do cursive letters. Since reading and writing are part of the same language process, it is believed that manuscript writing is preferable for its resemblance to the letters the child encounters when reading (Koenke, 1986). However, Duvall (1984) found that kindergarten children could do equally well in matching or reading manuscript, cursive, and italic handwritten letters compared to typeset letters. She concluded that the rationale for using manuscript because it resembles text was not justified. Apparently, the children in Duvall's (1984) study had established concepts of the invariant aspects of letters that allowed them to identify the letters in various contexts. This ability is what Ellis (1979, 1982) referred to as graphemes, the abstract specifications of a particular letter that can be expressed in a variety of forms.

Cursive has been suggested as preferable for learning disabled children for several reasons (Serio, 1970). The writing movement is more rhythmic, flowing, and efficient. Second, spacing is easier since letters in a word are not segmented. Third, there is less opportunity for directionality confusion and letter reversals of "b" and "d," "p" and "q," "m" and "w." In addition, Hagin (1983) suggested that, in cursive writing, words are dealt with as units rather than segmented letters and this benefits the learning disabled child.

Palmer, Zaner-Bloser, and D'Nealian methods

To date, there is no one agreed-upon best method of handwriting instruction. However, the most frequently mentioned commercial methods include the Palmer, Zaner-Bloser, and D'Nealian (Wood, Webster, Gullickson, & Walker, 1987) with italic handwriting as an alternative (DeHaven, 1983).

More than a century old, the Palmer method is the oldest method in use and includes vertical manuscript letters with a change over to slanted, flowing cursive in grade 3. The Zaner-Bloser program was begun in 1913 and, like the Palmer method, has markedly different manuscript and cursive letter forms. The D'Nealian method (Thurber, 1983, 1984) was devised in 1968 and differs from the two established methods in that the manuscript letters are simplified cursive letter forms that ease the transition from manuscript to cursive writing. Italic handwriting, which dates to the 16th century, has been revived in recent years (Dubay & Getty, 1980) because the letter forms require few lifts of the pencil and the child learns only one set of lower and uppercase letters.

Little research has been done on any of the methods, yet these methods are widely used. Wood and colleagues (1987) found no significant differences in legibility when the Palmer, Zaner-Bloser, and D'Nealian methods were compared for teaching 3,376 fourth and sixth grade children in South Dakota. These authors reported that they received 3,376 individual handwriting samples from children in 89 elementary schools, yet a subject demographics table depicted a total of 347 subjects. Since each subject was only evaluated on one sample, it was not clear whether the analysis of variance findings were based upon data from 347 subjects or 3,376 samples. If the authors reduced the original 3,376 samples for data analyses they did not indicate how this was done. Nonetheless, the finding that three prominently-used methodologies did not differentially affect handwriting legibility was relevant for considering handwriting instruction.

In a longitudinal study of 86 first and second graders in four classrooms, Farris (1982) using D'Nealian or Zaner-Bloser instruction found no significant differences in manuscript writing at the end of first grade. Students instructed with the D'Nealian method had fewer letter reversals and the author suggested that the continuous stroke aspect of the D'Nealian method prevented the development of perceptual motor difficulties found in more fragmented letter formations. For the second grade cursive writing, the Zaner-Bloser method resulted in significantly higher legibility ratings. However, for both grades, there was a significant correlation between reading ability and legibility of handwriting produced with D'Nealian instruction.

Duvall (1985) investigated the difficulty of four handwriting instructional systems: italic, Zaner-Bloser manuscript, D'Nealian manuscript, and Palmer cursive. This study provided useful criteria for calculating a letter difficulty score. However, comparisons between manuscript and cursive styles and promotion of the author's italic style as the preferred method are limitations of this study.

Letter as the basic unit in handwriting

In psychophysical analyses of handwriting features, Teulings, Thomassen, and van Galen (1983) found that the whole letter was the basic unit of writing in adult's cursive writing. Thus, emphasis on individual letter forms, regardless of which form is taught may be the most appropriate instructional approach. Using methodology similar to Teulings et al. (1983), Wing, Nimmo-Smith, and Elridge (1983) found that cursive letter forms were more consistently produced in the middle or end of the word than in the beginning. For example, when writing the words "advantage" and "amalgam" there was greater variability in subjects' formation of the letter "a" at the beginning of the word when compared from word to word than there was for the letter "a" compared within a word. Although an initial "a" varied from word to word, once the initial "a" for a word was written, the tendency was to write the letter "a" in similar fashion throughout the word. Apparently, a motor plan for writing the letter is generated at the beginning of a word and when that letter is used subsequently in the word, the same motor plan is used. Thus, when letters are evaluated for letter form, the letter order in the word may be considered.

Handwriting legibility

Five factors are commonly referred to when discussing factors affecting handwriting legibility: letter form, uniformity of slant, uniformity of alignment of letters, line quality, and letter and word spacing. Use of these factors to assess handwriting legibility date to Freeman's

(1915) scale for assessing school children's handwriting quality. Early studies of errors in letter formation and errors in spacing, alignment, slant, and line quality will be reviewed briefly.

Letters formation errors were studied in terms of letters that were most frequently illegible. In a study by Pressy and Pressy (1927) 16 graduate students analyzed 3,000 illegibilities in 650 papers written by elementary school children and high school and college students. Nearly one-half of the illegibilities were due to malformations of the letters r, n, e, a, d, and o. In Newland's (1932) study, 24 raters analyzed in excess of one million letters written by 2,381 persons including elementary school children, high school students, and adults. Four letters, a, e, r, and t, accounted for nearly half of the illegibilities in the three groups tested. Handwriting samples were from papers written by elementary, high school, and college students and from letters to the editor written by adults. Lewis and Lewis (1965) found that the letters q, g, p, y, and j were most frequently malformed in their analysis of 52 manuscript letters in the upper and lower case alphabet written by 354 first grade children. In the cursive writing of 1,000 sixth grade students, Horton (1970) found that 28% of all the letters were illegible. The letter "r" accounted for 12% of the illegibilities; the letters r, h, i, k, p, and z accounted for 30% of the illegibilities; and the letters a, b, c, i, l, m, n, u, v, and x accounted for 12%.

Common letter formations errors in manuscript and cursive writing considered together included n like u; r like i, e closed, d like cl, c like a, a like o, a like ci (Newland, 1932; Pressy & Pressy, 1927). Common manuscript errors included: reversals, omissions, additions, malalignments, mishapeness, rotations, retracings, inversion, incorrect relationship of letter parts, and sizes that are too large or too small (Lewis & Lewis, 1965).

Compared to common practice in educational research today, these early studies have several methodological flaws (Horton, 1970; Newland, 1932; Pressy & Pressy, 1927). Subjects' academic ability and age and cursive versus manuscript writing were not considered. Data analysis was limited to percentages rather than statistical significance. Methodology for selecting the handwriting samples to be analyzed and training of the raters were limited.

In a comprehensive study of factors that affected handwriting legibility, Quant (1946) considered legibility to be synonymous with readability. Handwriting legibility was measured according to the rate and accuracy by which material could be read at a given distance. Subjects' eye movements were filmed with a 35 mm motion picture camera and the number, location, and duration of each fixation of the eyes during reading was recorded. Legibility was measured for the average number of words read per regressive movement of the eyes to reread something. The following conclusions were made. Cursive writing was less legible than manuscript writing. Letter formation was the most important factor in readability. Compact spacing of letters (0.7 sixteenths of an inch) and words (3.1 sixteenths of an inch) was more readable as measured in amount of words read per eye fixation, than was widely spaced letters and words. Effects of overcrowding of letters or words was not studied. There was no difference in readability of lines placed 5/8" or 1/4" apart. Unevenly aligned writing did not significantly affect legibility. Irregularity of letter slant resulted in a decrease in the average number of words read each time the eyes had to look back a second time at a word. Results regarding the effects of the heaviness of the writing line were inconclusive.

The influence of handwriting variables, sex and age, on handwriting legibility was investigated in 588 children in grades 4, 5, and 6 (Andersen, 1969). The findings were that females are superior to males and that females write with a more perpendicular slant than do males. With increased age of subjects, the legibility, uniformity of size and uniformity of slant improve and writing size decreases. Improved legibility was related to larger writing and uniformity of slant. Larger sized writing was less uniform in size. Writing with a pronounced slant had a more uniform slant.

In summary, the types of letter formation errors (Lewis & Lewis, 1965; Newland, 1932; Pressy & pressy, 1927) and the five factors affecting legibility (Freeman, 1915; Quant, 1946) are frequently cited in the instructional and measurement literature on handwriting. The lists of letter formation errors and the five legibility factors have been used to devise handwriting checklists for classroom use (Cohen & Plaskon, 1980; DeHaven, 1983; Mercer, 1987; Petty et al., 1985) and for handwriting measurement (Anderson, 1969; Hammill & Larsen, 1983; Stott et al., 1985).

Handwriting rate

Rate of motor responding for handwriting has been calculated in letters per minute. Research on handwriting rate is minimal although rate is easily measured (Graham, 1986). Rates from the Zaner-Bloser Scales are frequently cited (Hammill & Larsen, 1983) and these rates are comparable to rates published in other evaluation systems (Phelps et al., 1985; Ziviani & Elkins, 1984). Rates in letters per minute for writing words by children grades one through seven are as follows: grade 1 - 25, grade 2 -30, grade 3 - 38, grade 4 - 45, grade 5 - 60, grade 6 - 67, and grade 7 - 74.

Computers and handwriting

Computers have been used as an alternative to handwriting for students with handwriting difficulties. Word processing allows students with handwriting problems to write, edit, and produce legible work that is self-enhancing (Bing, 1988). Computer-assisted instruction to improve handwriting motions was identified in only one study (Lally, 1982). The superiority of computers for speed and composition has not been supported. MacArthur and Graham (1987) found no differences in length, quality, and grammar in handwritten and computer-produced stories. Students revised at the end with handwriting and as they went along with computers. In contrast, Schanck (1986) found no significant differences in fourth grade students' editing and revising on handwritten versus computer stories. In terms of speed, handwriting was faster than use of a computer in adolescents with mild mental handicaps (Vacc, 1987) and in students with learning disabilities (MacArthur & Graham, 1987).

Single Subject Research

Applied behavioral analyses and single subject research in handwriting have been limited in number and have focused on the effects of feedback, self-correction, and reinforcement on rate and accuracy (Kerr & Lambert, 1982). Twelve studies were reviewed and are summarized here by describing the subjects, designs, measurements, dependent variables, independent variables, and results. Applied behavioral analysis was used in two studies that were nonexperimental field tests of handwriting evaluation instruments (Helwig, Johns, Norman, & Cooper, 1976; Jones, Trap, & Cooper, 1977).

Subjects included regular elementary school children (Jones et al., 1977; Trap, Milner-Davis, Joseph, & Cooper, 1978) children with handwriting problems (Helwig, 1976), learning disabilities (Blandford & Lloyd, 1987; Graham, 1983; Kosiewicz, Hallahan, & Lloyd, 1981; Smith & Lovitt, 1973), mental retardation (Clark, Boyd, & Macrae, 1975; Stowitschek, Ghezzi, & Safely, 1987), low socioeconomic background (Fauke, Burnett, Powers, & Sulzer-Azaroff, 1973), and gifted abilities (Salend, 1984). The design most frequently used was the multiple baseline design (Blanford & Lloyd, 1987; Clark et al., 1975; Graham, 1983; Helwig, 1976; Salend, 1984; Stowitschek et al., 1987; Trap et al., 1978) with reversal designs used in three studies (Fauke et al., 1973; Kosiewicz et al., 1981; Smith & Lovitt, 1973). Multiple baseline design was preferred since reversal of the motoric academic skill being trained was undesirable (Kerr & Lambert, 1982).

The lack of valid and reliable measures of handwriting legibility was apparent in the use of researcher-developed measurement techniques in most studies. Transparent overlays were used to judge 1, 2, and 3 mm leeway of the approximation of the child's letter form to model letter forms (Fauke et al., 1973; Helwig, 1976; Helwig et al., 1976; Jones et al., 1977; Trap et al., 1978). Stowitschek and colleagues (1987) developed a correction template with white letters against a black background and used semitransparent worksheets that were placed over the templates for evaluation. Criteria for judging letters were developed for assigning points to letter form. For example, Blanford and Lloyd (1987) assigned one point for each criterion when words were 1/8 but not more than 1/4 inch apart and when the letter was not more than 1/16 inch above or below the line; correctly formed; the correct height; and one-half space tall, if lower case. This rating system was tested on four non-learning disabled students whom the classroom teacher identified as having average handwriting.

Dependent variables consisted of rate of percentage correct letters. Children received training in 2 letters (Graham, 1983; Smith & Lovitt, 1973); 4 letters (Salend, 1984); 8 letters (Stowitschek et al., 1987); 10 letters (Helwig, 1976; Jones et al., 1977; Trap et al., 1978); or the 11 letters in their name (Fauke et al., 1973). Daily journal writing (Blanford & Lloyd, 1987), paragraph copying (Kosiewicz et al., 1981), and completing biographical information forms (Clark et al., 1975) were dependent variables in three studies.

Self-teaching and self-assessment comprised the independent variables in most studies. Independent variables included self-instruction (Blandford & Lloyd, 1987; Graham, 1983; Koseiwicz et al., 1981), self-evaluation

(Blandford & Lloyd, 1987; Kosiewicz et al., 1981; Stowitschek et al., 1987), self-verbalization of errors (Helwig, 1976), and self-recording (Jones et al., 1977). Careful modeling of letter formation (Salend, 1984; Trap et al., 1978), the use of modeling and yarn letters on cards (Fauke et al., 1973), comparisons of b and d reversed letters (Smith & Lovitt, 1973), and emphasis on practice (Clark et al., 1975) were used in handwriting instruction.

All the studies reported improvements in handwriting. Thus, self-assessment, self-instruction, careful modeling, and practice were effective techniques for improving handwriting. Children were reliable in assessing their own work (Jones et al., 1977). An average of 48 practice minutes were needed to reach criteria on a set of eight letters in children with mental retardation (Stowitschek et al., 1987).

Improvements showed some generalization to other settings (Blanford & Lloyd, 1987; Stowitschek et al., 1987) and to the ability to write letters for which intervention had not been provided (Helwig et al., 1976; Jones et al., 1977; Trap et al., 1978). However, Graham (1983) found that the improvements in the ability to write the two letters for which intervention had been provided did not carry over to four other letters which were merely practiced but for which intervention was not provided. He concluded that this handwriting training was not cost-effective. He suggested that the complexity of the treatment procedures and too few training sessions may have contributed to the results. The children in this study verbalized the movements as they formed the letters and Graham (1983) posed that this technique could interfere with, rather than enhance, the writing motion.

Summary

The literature on handwriting has been reviewed in terms of handwriting as a neuromotor process. A neuropsychological model of graphomotor skills was proposed and motor cortices, psychophysical features of handwriting and grip and posture were discussed. Visual aspects of handwriting were described and attentional mechanisms for writing were reviewed. Limitations of measurement tools for assessing handwriting were described. Finally, handwriting instruction was discussed with emphasis upon single subject intervention in handwriting problems.

In this literature review, an instructional issue that has not received attention in the literature was identified: distance of the stimulus copying tasks. In summary, the literature reviewed in this chapter on motor, visual, attention, instructional, and measurement issues related to handwriting has provided relevant and useful information for considering stimulus distance for copying by school children. In the next chapter, the methodology for the study is presented.

CHAPTER III
METHODS

Introduction

The purpose of this study was to investigate the effects of three distances of the stimulus from the subject on handwriting legibility, as measured for letter formation and word spacing, of children performing a copying task. The three stimulus distances as measured from the stimulus to edge of the table next to the child were 0.5 meters from the stimulus placed on the desk, 3 meters from the stimulus placed on the chalkboard, and 6 meters from the stimulus placed on the chalkboard.

These three distances are commonly used for copying instruction in the regular classroom setting. They have been used when the child copies material placed on the desk or when the child copies material written on the chalkboard while seated in either the front row of desks or in the back row of desks. Letter formation and word spacing are features commonly addressed in assessment of handwriting legibility.

Methods and procedures of the study are presented in this chapter. The chapter includes the following eight sections: questions, subjects, setting, personnel, dependent variable, independent variable, design, and treatment of the data.

Questions

To address the purpose of the study, two research questions were posed. The questions are stated below.

1. What are the effects on the level, variability, and trend of letter formation scores with copying stimuli placed at 0.5 m, 3 m, and 6 m distances from the subject?

2. What are the effects on the level, variability, and trend of word spacing scores with copying stimuli placed at 0.5 m, 3 m, and 6 m distances from the subject?

Subjects

Subjects included 13 elementary school children who attended a public school and had been nominated for the study because of poor handwriting performance in school. Subject demographic data are presented in Table 1 and include sex, age, race, intelligence quotient (IQ) when available, first grade vision screening results, services being received, handwriting grades, and reading and mathematics achievement test scores. Vision was normal for all subjects except for one subject with 20/100 vision who was referred for an eye exam and one subject whose vision was corrected with glasses. Of the 13 subjects, 3 received services in a resource room for varying exceptionalities; 4 received extra help for academic problems in Chapter I

Table 1

Subject Ages, Race, Vision, Services, Intelligent Quotient, Handwriting Grades, Achievement Test Percentile, and District Stanine

					I.Q. WISC			Grade	Achievement Tests CAT %tile/district stanine	
Subject	Age	Race	Vision	Services	V	P	FS	HW	Reading	Math
1	7-7	B	20/30	EH, SL			+83	N	56/5	53/5
2	7-5	B	20/30	EH, SL	++97	75	85	N-	1/3	10/2
3	8-1	B	20/25	EH			+96	S-	74/6	51/5
4	8-2	B	20/100	Ch 1				S-	3/3	7/3
5	8-0	W	WNL	Ch 1			+++98	S	20/6	38/5
6	7-11	W	20/30	Ch 1	++90	91	89	N	7/2	15/3
7	7-11	B	20/30	Ch 1				S-	9/2	40/4
8	7-3	W	20/20		+++107	108	109	S-	*46/5	*44/5
9	7-4	H	WNL					N	39/4	48/5
10	8-10	W	WNL					S	**64/6	**77/7
11	8-7	W	20/30	SL				S-	42/5	82/7
12	7-3	W	20/30					S	62/6	58/5
13	7-8	W	20/20	G				S-	87/7	85/7

CAT California Achievement Test
*Stanford Early School Achievement Test
**Comprehensive Test of Basic Skills
+Kaufman Assessment Battery for Children
++Weschler Intelligence Scale for Children
+++Test of Nonverbal Intelligence
++++Weschler Preschool and Primary School of Intelligence
EH Emotional Handicap
SL Speech and Language
Ch 1 Chapter 1 Program
G Gifted
Grades: S = Satisfactory; N = Needs Improvement; U = Unsatisfactory
WNL Within Normal Limits

program; and 6 had been identified by the classroom teacher as having difficulty with handwriting, but they were not receiving additional services. The 3 subjects in the resource room had been identified as having an emotionally handicapping condition. This condition is defined as "resulting in persistent and consistent maladaptive behavior, which exists to a marked degree, which interferes with the student's learning process and which may include but is not limited to any of the following characteristics" (Alachua School District, 1989, p. 57). Characteristics include inadequate academic progress, difficulty in interpersonal relationships, inappropriate behavior, pervasive unhappiness or physical symptoms related to school or personal difficulties (Alachua School District, 1989). These children had received one semester of services in the resource room during the previous school year. They were identified by the varying exceptionalities teacher as having handwriting problems.

The 4 subjects in the Chapter I program were identified for this service because of their low math and reading scores on the California Achievement Tests, a behavioral checklist, current academic performance, and teacher recommendation (School Board of Alachua County, 1989). The Chapter I program is a federally-funded program that provides a self-contained basic skills classroom for children in grade 1 and a basic skills development laboratory for children grades 2-5. Children receive 240 minutes of instruction per week that includes direct instruction in reading and math and computer-assisted instruction. Subjects in the Chapter I program were identified for this study through teacher referral.

The remaining 6 subjects were identified by the four second grade teachers as the children in the class having the most difficulty with handwriting. Other than one subject who was in a program for the gifted, these children had never received, nor had been referred for, nor were currently receiving any special services for academic or other problems. The criteria for selecting students for the program for the gifted include: intelligence quotient of 130 or above, significantly above average academic achievement, teacher-identified characteristics and needs that are not being met in the regular classroom (Alachua School District, 1989).

Teacher referral was verified by administering a sample nonword sentence to 22 children in one classroom that had five children referred for the study. The stimulus sentence was placed at the 6-meter distance. The children wrote their names on the back of the paper and the writers were not identified until all scoring was completed. Using visual inspection, the investigator sorted the papers into the good, fair and poor stack. There were eight samples in the "poor" stack, accounting for 36% of the sample. The investigator and two raters used the Error Analysis of Children's Handwriting (EACH) to independently score the letter formation and word spacing of the eight papers with the poorest handwriting. In this group of eight children, the four children who had been referred by the teacher had the lowest scores with 92% agreement among the three raters. The fifth child referred by the teacher was absent the day the sample was taken. Because of illness, this child was subsequently replaced in the study by a child who was not originally referred to the study but who had the same score as one of the four lowest scoring children. The teacher strongly endorsed the inclusion of this child in the study and noted that she thought that she should have referred him when she referred the other five children. Thus, all four of the children originally referred by the teacher had the lowest scores on a handwriting sample scored independently by the investigator and two raters.

Subjects were selected who were 7 or 8 years of age, male, right handed for writing, had parental consent and were not taking any medication. Subjects had not been identified in the educational system as having motor, sensory, or language disorders such as cerebral palsy, blindness, deafness, or aphasia. One of the children wore glasses to correct a refractive error, one had been referred for an eye exam due to the vision screening score of 20/100. The remaining subjects had passed the first grade visual screening. All the subjects had at least one year of instruction in the D'Nealian (Thurber, 1987) approach to handwriting that is the handwriting method stipulated by county school board policy (S. Hollenger & M. Buchanan, personal communication, April 21, 1989).

Permission to conduct the study was obtained through the University of Florida Institutional Review Board and the Alachua County School Board. A parental permission form was signed by the parents of the participating students.

Setting

The activities of the study were conducted at Terwilliger Elementary School in the school library and on the school cafeteria stage. These settings versus the regular classroom setting were chosen in order to avoid the distractions posed in a regular classroom and to prevent interruption of regular classroom procedures. Sessions were scheduled during the times when these settings were quiet. Both settings were well-lighted and were devoid of wall decorations. In the library, the room had three walls and the open end of the room was open to the main library. Portable screens were used to prevent the subject from viewing activity in the library. In the cafeteria, curtains surrounded the testing area on all sides. Easels supporting the copying model were situated in front of the subject and could be moved towards or away from the subject to provide the desired stimulus distance. A child-sized table and chair were properly fitted to the child's height, as specified by Benbow (1988). The posture used for the study included the child positioned squarely on the chair. With the child's arm hanging straight down, the height of the writing surface was two inches above the bend in the elbow.

Personnel

Personnel involved in the study included four research assistants, three raters and the investigator. The research assistants and one of the raters were undergraduate students who were enrolled in a course or had taken a course in applied behavior analysis and had experience with timing children's behavior. Assistants were trained to position the stimulus in relationship to the subject and to collect the handwriting samples. The purpose of the study was not discussed with the assistants and the results of daily handwriting sampling were not disclosed. Two raters were doctoral students in special education with experience in tests and measurements and who had completed required doctoral courses in statistics. The investigator scored the letter formation and one of the raters scored the word spacing. The other two raters participated in the establishment of interrater agreement prior to the outset of the scoring process.

The raters were trained by the investigator to use the EACH. On independent ratings of handwriting samples from 8 subjects in a regular classroom, the investigator and two raters achieved 80% or better agreement on 88% of the subjects for letter formation and for word spacing ratings (see Table 2). More specifically, for letter formation, interrater agreements were 90% or more on 18 of the 24 interrater agreements. Median interrater agreements for the three raters were 84%, 93%, and 96%, and the agreements ranged from 71% to 99%. For word spacing, the interrater agreements were 90% or more on 13 of the 24 interrater agreements. Median interrater agreements for the three raters were 83%, 86%, and 88%, and agreements ranged from 50% to 100%.

Interrater agreements between the investigator and the rater who scored the word spacing were observed for 10 subjects prior to the outset of the scoring of samples from the subjects (see Table 2). Interrater agreements were 100% on eight samples, and 80% and 75% on the remaining two samples.

Dependent Variables

A criterion-based handwriting checklist, Error Analysis of Children's Handwriting (EACH), was devised for this study and used to assess the subject's daily handwriting samples. This checklist will be described in this section and is shown in Appendix A.

Daily handwriting samples were assessed in two areas: word spacing and letter form. Rate of correct responding was used because rate is a sensitive measure of behavioral changes and it provides a standard measure to compare

Table 2

Percentage of Agreement of Rater Pairs Prior to and During the Study

	Letter Formation			Word Spacing			
	Rater Pairs						
Sample	1&2	1&3	2&3	1&2	1&3	2&3	1&4
			Prior to Study				
1	96	92	88	88	100	88	100
2	96	90	94	75	50	67	80
3	95	84	80	100	100	100	100
4	71	94	67	88	100	88	100
5	99	96	97	83	100	83	100
6	99	90	90	90	100	100	100
7	99	92	93	86	86	100	100
8	94	90	96	100	100	100	100
9							100
10							75
			During Study				
1	95						100
2	83						100
3	98						100

behavior over several days (Tawney & Gast, 1984). Handwriting legibility was assessed in two rates: number of correctly spaced words per minute (WPM) and number of correctly formed letters per minute (LPM).

Word spacing was assessed by measuring the space between the words. If the space after the word was not less than 6 mm or more than 12 mm, the word was scored 1 as not having a spacing error. In the absence of any normative data on spacing, a spacing criteria was determined by examining D'Nealian workbooks (Thurber, 1987) and measuring the spacing between words in models used for children's copying practice. The rate of correctly spaced words was calculated by dividing the number of correctly spaced words (1 point each) in the sample by the 2 minutes for the sample.

Letter form (Stott et al., 1985) was assessed by examining each letter for five possible errors: reversal, incomplete letter, last stroke of letter in the wrong place, poor line quality, and incorrect alignment or size. Each letter was scored 0 to 5 points. For each of the five errors, 1 point was assigned if the letter were deemed to be correct and free of that error and a zero was recorded for each error that was found. Criteria for each of the five errors are described below.

1. The letter was reversed, inverted, or rotated (such as b/d, p/q, g/q, s/z, u/n, w/m).

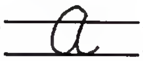
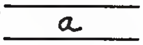
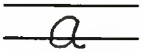
2. The letter was incomplete (such as t or f not crossed, i or j not dotted, e without an eye, q without a tail); or the letter was incompletely closed with a gap measuring more than 1 millimeter; or ascenders (b, d, f, h, k, l, t) or descenders (g, j, p, q) were too short.

3. The ending stroke of the letter was incorrect or positioned in the wrong place such as an additional stroke added to the letter m.

4. Line quality was poor in that the letter had bent, shaky, irregular, broken, or jagged lines, crumpled curves or collapsed loops.

5. Letter alignment and letter size were treated together as one error type for measurement purposes in this study. Petty et al. (1985, p. 301) stated: "Alignment and size are closely integrated and should be studied together." Letter alignment refers to the position of the letter in relationship to the writing lines (Hammill & Larsen, 1983) and is usually assessed by identifying the letters that are above or below these lines (Petty et al., 1985). Size refers to how well the letter is positioned between the writing line (Hammill & Larsen, 1983) and is usually assessed by determining how well the letter conforms to the space between the lines (Petty et al., 1985). For example, a lower case "a" should fit in the lower one-half of the space between the lower and middle lines of the paper. Since size and alignment are so closely related (Petty et

al., 1985) and are measured in the same way, that is, by measuring the position of the letter or its parts in relationship to the line, size and alignment were considered together.

For the measurement purposes of assigning a point value to error criteria, the separate scoring of size and alignment was not used in this study because to do so would result in a double penalty for the same error. If size and alignment were considered separate errors, yet size and alignment were judged in relationship to the writing lines, it would be difficult to determine a size versus an alignment error. For example, all of the following errors can be measured in relationship to the writing lines: an "a" that is so large that it goes beyond the guidelines on the writing paper (); an "a" that is so small that it does not come to the guidelines (); or an "a" that appears to be the correct size but is malaligned, that is, placed below the baseline (). For the "a" that is placed below the baseline, an alignment error would be determined by measuring the distance below the baseline. Since distance below the baseline was used to determine an alignment error, the rater would have no objective measure of size and would have to make a judgment that the letter would have been the correct size if it had been placed on the line. Were the rater to measure the distance below the baseline to determine a size error, the letter would by doubly penalized for essentially the same problem: a portion of the letter was below the baseline. Thus, although size and alignment are two separate problems in handwriting legibility, for the purposes of measurement in this study, they are considered together.

Using as a guide the baselines, dotted middle lines and upper lines of the primary school paper, a letter that was more than 1 millimeter from its relevant lines was determined as having a size/alignment error. Letters a, c, e, i, n, m, n, o, r, s, u, b, w, x, and z were scored one if the letter came up to but did not exceed by more than 1 millimeter below the writing line. Letters with ascenders (b, d, f, h, k, l, and t) were scored 1 if the descender dropped to, but did not exceed by more than 1 millimeter the dotted middle line below the writing line. If the ascender or descender did not come to the appropriate line, it was scored 0 as an incomplete letter under criteria two and scored 1 under the alignment/size criteria.

In cases where the subject miscopied a word, the letters in the word were scored using the procedures described above. Examples of miscopying included transposed letters (paj for ajp), substitutions (ajj for ajp) and omissions (aj for ajp).

Independent Variables

The stimuli for the copying tasks consisted of nine sentences composed of nonwords devised by the investigator.

The use of nonwords is common in neuropsychological studies (Ellis & Young, 1988; Roeltgen, 1985). Nonwords rather than actual words were used in this study for four reasons: to maximize attention, to minimize boredom, to equalize language experiences, and to emphasize visual-motor aspects of the copying task. First, nonwords would have novel appeal and require careful attention to the individual letters composing each "nonword," thus maximizing attentiveness. Second, since the subjects would be required to write three sentences several times, boredom with a repetitious task might be minimized with the use of unusual material. Third, the use of nonwords would equalize the effects of reading experience in that all subjects would begin the study with no experience with the task stimuli. Fourth, the visual-motor aspects of copying could be isolated if the meaning of what was written, i.e., the semantic influences on writing (Roeltgen, 1985), were reduced.

Each copying task included three stimulus sentences with 50 letters per sentence. Nonwords included the letters found to be most often illegible (Coleman, 1970; Graham, 1986; Horton, 1970; Lewis & Lewis, 1964, 1965; Pressy & Pressy, 1927; Walker, 1989), the letters most frequently appearing as initial consonants in 17,000 most frequently used words (Hanna, 1966), letters from each letter group (Thurber, 1987) and letters likely to be reversed (Smith &

Lovitt, 1973). The "problem" letters numbered 19 and included a, b, d, e, g, h, i, j, k, n, o, p, q, r, s, t, u, y, and z. Nonwords were created from the first grade reading list used at the school by substituting "problem letters" for the initial letter in the word to create as many nonwords as possible from each real word. Nonwords were composed of two, three, four, and five consonant (C) and vowel (V) combinations including CV, VC, CVC, CVVC, CVCC, CCVC, CVCV, VCVC, CCVCC, CVCCC, CVCVC, CVVCC, CCVCV, CCVVC. Nine sentences were constructed by randomly selecting nonwords using a table of random numbers (Mendenhall, 1979). Sentences included one 1-letter word, one 2-letter, one 3-letter, six 4-letter, and four 5-letter words, for a total of 50 letters. Letter, word, and sentence lists used to devise the stimuli are shown in Appendix B.

The stimulus sentences were handwritten with black ink on a chalkboard replica made of white paper or on primary-lined white paper. The chalkboard replica was used for the 3-meter and 6-meter stimulus distances and the primary-lined paper was used for the stimulus placed on the table at the 0.5-meter distance. The chalkboard replica was the size of a chalkboard (1.5 m x 1 m) and had solid lines 13 cm apart and a dashed center line equidistant between the two solid lines. The spacing of the chalkboard lines was derived from measurement of chalkboard lines in four regular second grade classrooms. The primary-lined paper was the size of regular writing paper (20 x 27 cm) and had solid lines 1.3 cm apart and a dashed center line equidistant between two solid lines. The dashed lines on the chalkboard replica and the primary-lined paper served as a height guide for half-spaced letters that were written on the line (such as the letter "a") and for letters with descenders that were written one half space below the solid line (such as the letter "p"). The D'Nealian (Thurber, 1987) letter forms were used in the stimuli that the children copied.

Writing paper used by the subjects consisted of primary paper with solid lines 1.3 cm apart and a dashed center line between the two solid lines. Writing implements were ordinary number 2 pencils for writing.

Prior to the initiation of the study, the locations of the three stimulus distances in the classroom were determined. These distances were derived from measurements in four elementary school classrooms in a public school. Each classroom had the desks arranged in different configurations in the room. The stimulus distances selected for this study were the averages of the measurements in these four classrooms for desktop depth (0.5 m), the distance from the front row of desks to the chalkboard (3 m), and the distance from the back row of desks to the chalkboard (6 m).

For the first condition, the stimulus sentences written on primary paper were placed upright in a recipe book holder. The holder was located at the far edge of the desk from the subject and centered directly in front of the subject, 50 cm from the edge of the table next to the subject. This distance provided about 30 cm of work space for the subject and another 20 cm of space beyond the work space to the holder.

For the second and third stimulus distance conditions, seating positions 3 m from the chalkboard and 6 m from the chalkboard were located. The locations of these stimulus positions were marked inconspicuously with masking tape on the floor. The research assistants checked to see that the seats were properly relocated each day after the room had been cleaned.

The subjects were timed for 2 minutes while copying the stimulus sentence. It was anticipated that it would take longer to copy a nonword sentence than a sentence with regular words (Ellis & Young, 1988). However, 2-minute timings were projected as ample time to copy a 50-letter sentence since letter per minute rates for children in grade 2 have been found to be about 30 letters per minute (Hammill & Larsen, 1983; Phelps et al., 1985; Ziviani & Elkins, 1984).

The procedural sequence for each session was as follows. Introductions were made and the child chose the toy (car, figurine, or the like) that he wanted to play with on his break from the writing task. The toy was put aside. The assistant checked to see that the child was seated with proper posture at the table. The first stimulus was shown to the child, instructions were given, and the child's writing was timed for 2 minutes. The child then took a 2-minute break to play with the toy and the assistant got the next stimulus distance ready. This sequence of events was repeated for the second and third stimulus positions. The session was completed in 15 minutes.

The following instructions were given to the subjects by the assistants. "You will be copying three sentences for me. You will take a break for two minutes between each sentence and while you are on break, you can play with one of these toys (show toy car, figurine, etc.). When it is time to write you have to put the toy away when I say to so that we will have time to finish the writing. I want you to copy the sentence here (point to the paper on the desk or to the chalkboard) onto your paper. Can you read these words? No, they don't make any sense, do they. That is the way it will be. You will be copying what we call nonwords. Do not try to read them or to understand what they mean. I just want you to copy them as best you can. While you are writing, we will not be doing any talking."

The timing of the subject's response was explained to the subject using the following: "It is important for you to try to write well. You will be timed, but it is more important for you to write well than to try to write fast. Get ready to write. I will tell you when to begin writing and you are to continue writing without stopping until I tell you to stop. If you come to the end of the sentence before I have told you to stop, go back to the beginning of the sentence and copy the sentence over again. When you are finished for today, you can select an item from my "goody bag" for doing a good job."

The research assistants were trained to time the subject's writing response. The assistants cued the subject when the begin and as soon as the child put his pencil to the paper, the assistants began timing. Timing was terminated at 2 minutes. If the subject interrupted the task to erase a mistake, talk, to look around the room, or the session was interrupted in some other way, the assistants stopped the timing and started it again as soon as the pencil went to the paper to write.

Proficiency of the assistants' abilities to time handwriting behavior was established in the training sessions. Training included timing when the child was distracted. Assistants timed each other or the investigator with 99% proficiency.

The investigator and one rater scored the handwriting samples using the EACH checklist. For each sample, the rate of correctly spaced words per minute and the rate of correctly formed letters per minute were calculated.

Blind scoring of the children's word was insured by having the research assistants assign the subjects to the stimulus distance conditions. This was accomplished by having the assistants assign a code to the three stimulus distances and to use this code throughout the study but not to tell the investigator what the code meant until the end of the study. This way, as the investigator was evaluating the sample, the investigator did not know which stimulus distance a given handwriting sample represented but knew, for example, that stimulus distance was the same across days of the study for a given subject.

To control for order effects of stimulus distance presentations and to control for practice effects of the stimulus sentences, the research assistants constructed a chart for counterbalancing the six combinations across the nine sentences. Parameters for scheduling the stimulus presentations were that all six stimulus distance orders had to occur during the first six days of the study and that the same sentence could not be used during any one-day session, nor in two consecutive days. During the first six days of the study, each subject was observed in all six possible orders of the stimulus distances and were exposed, as equally as possible, to the nine sentences. The six distance orders were then again assigned for the next six days of the study. The daily handwriting sample for each child included three different sentences, copied from model sentences placed at the three distances. On each sample of handwriting, the assistant wrote the child's name code, the date, and the stimulus distance code. This way the raters knew the child's coded name, the date, and the coded stimulus positions.

Design

An alternating treatments design (ATD) (Tawney & Gast, 1984) was used to compare the effects of three stimulus distances on handwriting legibility. This design was selected to address the questions posed in this investigation because several interventions can be compared at once and sequencing effects are minimized. In addition, the ATD was preferable over a withdrawal or reverse design, since reversibility of handwriting skills was undesirable or impossible (Kerr & Lambert, 1982).

Using the ATD, treatments were alternated within sessions and each treatment condition was implemented once each day. The three stimulus distance conditions were counterbalanced for a total of six combinations of order for the three distances. The six combinations of order for the three stimulus distances were counterbalanced with the nine stimulus sentences for 12 treatment sessions (see Table 3).

Table 3

Alternating Treatments Design (ATD): Counter-balancing Six Combinations of Order for the Three Stimulus Distances, Nine Sentences, and 12 Days of the Study

---

Three stimulus distance conditions:

1. 0.5 meters
2. 3 meters
3. 6 meters

Six combinations of order for the three stimulus distances:

1. 0.5 meters, 3 meters, 6 meters
2. 0.5 meters, 6 meters, 3 meters
3. 3 meters, 0.5 meters, 6 meters
4. 3 meters, 6 meters, 0.5 meters
5. 6 meters, 0.5 meters, 3 meters
6. 6 meters, 3 meters, 0.5 meters

Counterbalancing of the Six Combinations of Order for the Three Stimulus Conditions and Nine Sentences Across 12 Days

Sentence-Stimulus Distance

Day 1	Day 2	Day 3	Day 4
1 - 3m 3 - 6m 6 - 0.5m	8 - 6m 2 - 3m 7 - 0.5m	4 - 6m 5 - 0.5m 9 - 3m	1 - 0.5m 3 - 6m 6 - 3m
Day 5	**Day 6**	**Day 7**	**Day 8**
8 - 0.5m 2 - 3m 7 - 6m	4 - 3m 5 - 6m 9 - 0.5m	1 - 6m 3 - 0.5m 7 - 3m	8 - 3m 2 - 0.5m 4 -6m
Day 9	**Day 10**	**Day 11**	**Day 12**
9 - 0.5m 5 - 3m 6 - 6m	1 - 6m 3 - 3m 7 - 0.5m	8 - 3m 2 - 6m 6 - 0.5m	4 - 0.5m 5 - 6m 9 - 3m

Treatment of the Data

The data collected from samples of 13 subjects were displayed in graph form and then analyzed for level, variability, and trend. Methods for displaying data and for data analysis are discussed in this section.

Simple line graphs were used to display subject data by condition. For each subject, simple line graphs displayed targeted data points including the rate of correctly formed letters per minute and the rate of correctly spaced words per minute for each condition.

Boxplots were used to display the overall level, variability, and symmetry of the data and any data points that were very different from the rest of the data. A boxplot was provided for each stimulus condition. Comparison of boxplots for the three stimulus conditions revealed the relative levels and variability of the data cross the three stimulus conditions. Boxplots provide a visual display of comparisons of the medians. When the shaded areas of two boxplots do not overlap, this indicates significant differences in the population medians at a 5% level (Velleman & Hoaglin, 1981).

To examine the relationship between independent and dependent variables, level (or magnitude), trend (or slope), and variability (or range) were analyzed (Tawney & Gast, 1984). Boxplots and summary tables were used to examine level and variability of the scores. Line graphs were used to examine the data slope or "steepness of the data path across time" (Tawney & Gast, 1984, p. 162). Data slopes were visually inspected to compare the data paths of the three stimulus distances and, thereby, to observe for differential effects of the independent variable. In addition, significant accelerating or decelerating slopes were identified by using regression analysis to predict scores across time. The direction of the trends, accelerating or decelerating, were determined by the sign (+ or -) of slope coefficient for each trend.

Summary

The methods for investigating the effects of three stimulus distances upon handwriting legibility were described in this chapter. Questions were posed regarding the effects of stimuli placed at the desk and at two distances on the chalkboard upon two handwriting legibility variables: letter formation and word spacing. A single subject research study was proposed to address those questions in second grade children with handwriting problems. A public school setting was described. Methods and personnel used to collect the handwriting samples were explained. Procedures and rationale for a criterion-referenced legibility checklist for evaluating the handwriting samples were provided. Finally, an alternating treatments design and data analysis were proposed. In the next chapters, the results and discussion of this investigation will be presented.

CHAPTER IV
RESULTS

Introduction

The purpose of this study was to investigate the effects of three distances of handwriting stimuli on handwriting legibility of second grade children with handwriting difficulties. The stimuli were placed in front of the child at distances of 0.5 m, 3 m, and 6 m. Handwriting legibility was judged for correct letter formation and correct word spacing. To address the three stimulus distances, two research questions were posed regarding the effects of each stimulus distance on the level, variability, and trend of scores of correctly formed letters per minute and on the number of correctly spaced words per minute. The two questions were tested using a single subject, alternating treatments research design. The alternating treatments design was used to compare several interventions while minimizing sequencing effects (Tawney & Gast, 1984).

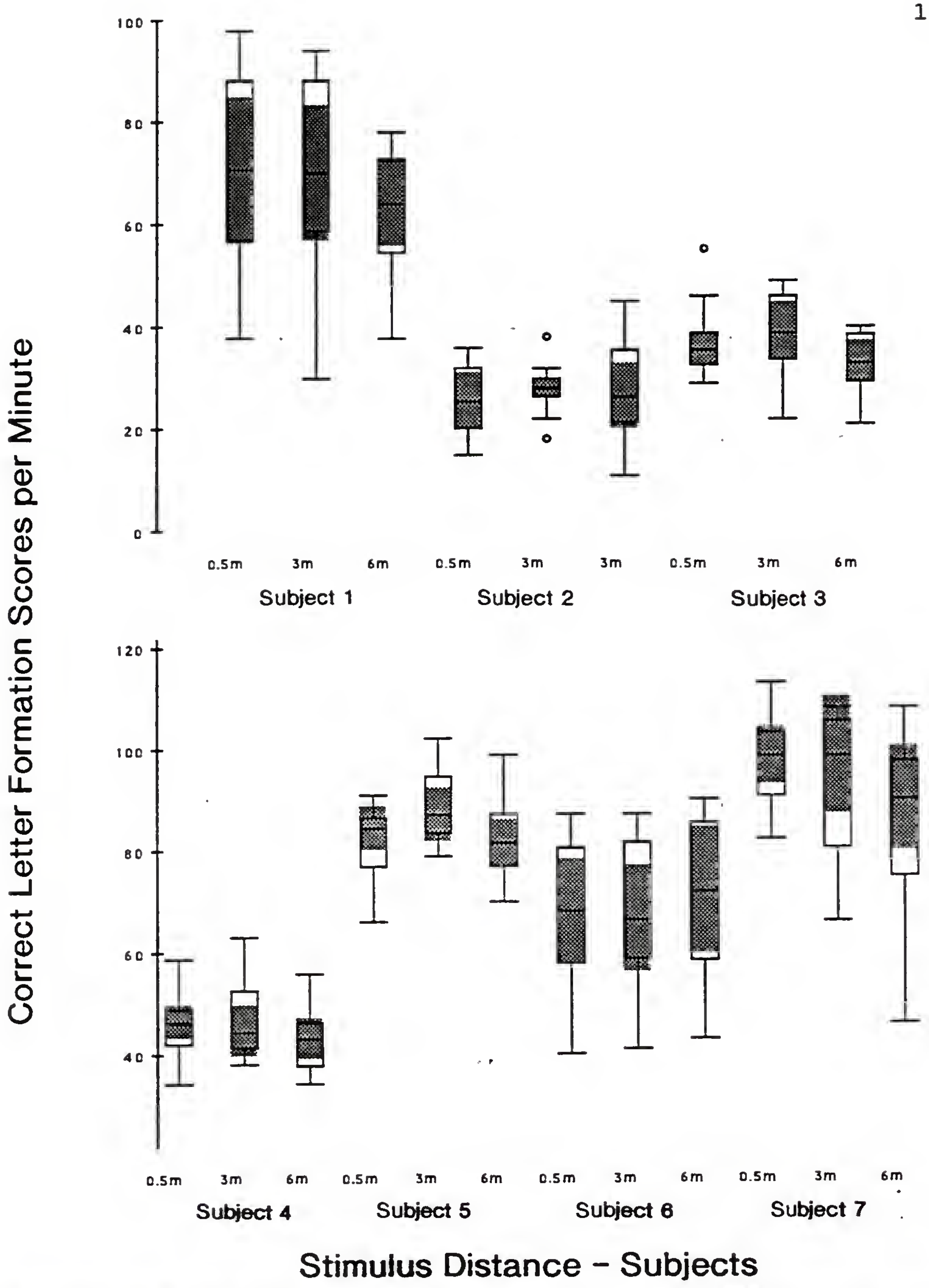
In this chapter, the presentation of the data is organized according to the two questions. First, the methods for analyzing the data are explained. Second, each question is stated. For each question, the level, variability, and trend of the data are summarized. Last, the chapter is summarized. In keeping with single subject design, data are presented in graphic displays by subject.

Analysis of the Data

The letter formation and word spacing scores for copying performance at 0.5 m, 3 m, and 6 m stimulus distances collected from the handwriting samples of the 13 subjects are displayed in graphs (Figures 2-5). Summary data including the median, interquartile ranges, and slope are presented in Tables 4-7. Raw data for each subject are presented in Appendix C.

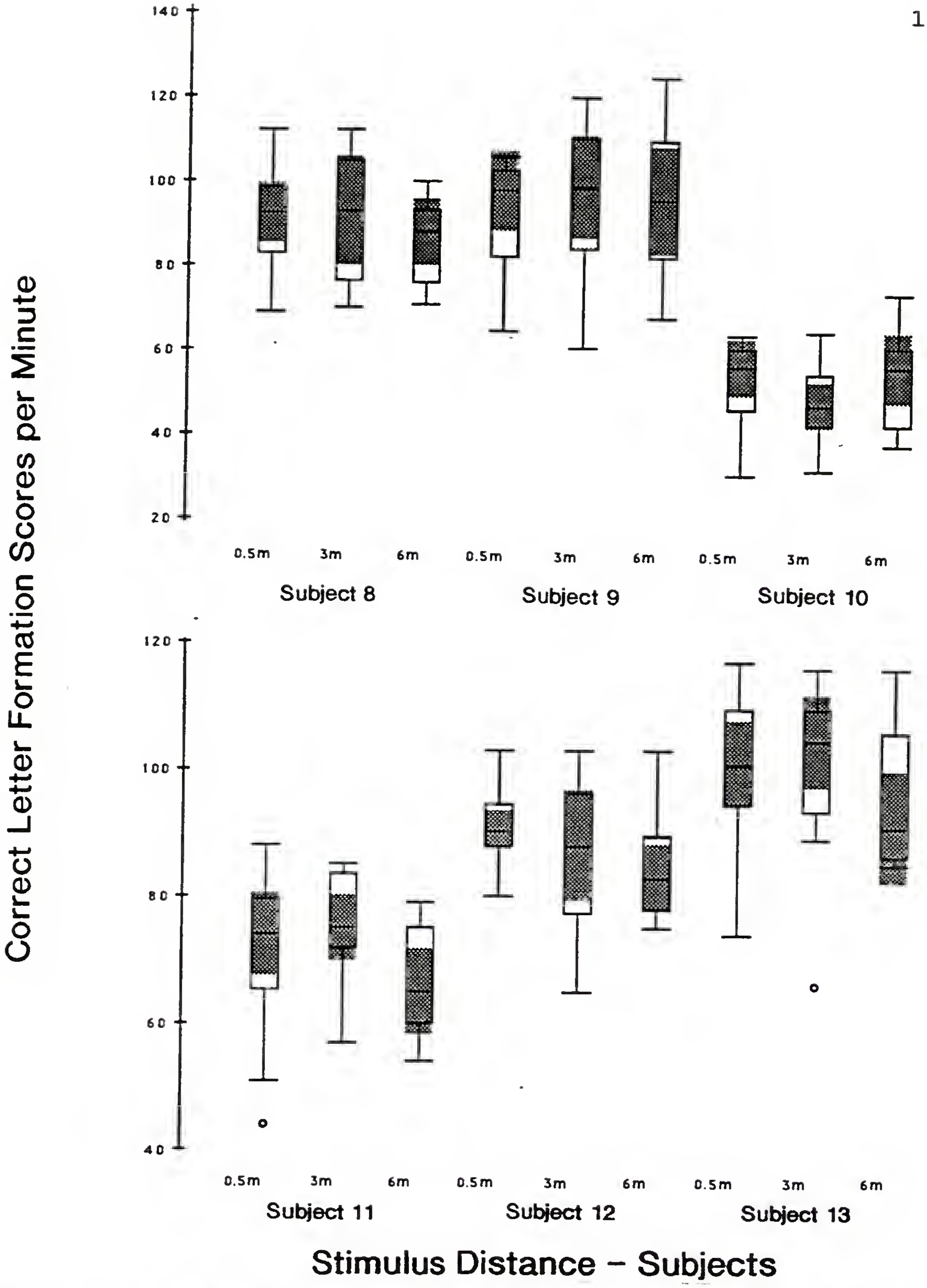
In the graphs and tables, subjects are identified by subject numbers 1-13. Subjects had been identified by their teachers as having difficulty with handwriting. Subjects 1-3 also received services for an emotionally handicapping condition. Subjects 4-7 received services in the Chapter 1 program for children with low achievement test scores and at-risk for learning problems. Subjects 8-13 were not receiving any special services but were identified by the classroom teacher as having handwriting problems. An exception in the last grouping of subjects was subject 13 who was in a program for gifted children.

Data were analyzed for level (median scores), variability (interquartile ranges), and trend (data slope). Level and variability of the data are graphically depicted



Note. Maximum possible score about 125 points. Ordinate scales vary for each graph according to the subject's scores. Non-significance indicated when shaded areas of boxplots overlap.

Figure 2. Boxplots for letter formation.



Note. Maximum possible score about 125 points. Ordinate scales vary for each graph according to the subject's scores. Non-significance indicated when shaded areas of boxplots overlap.

Figure 2--Continued.

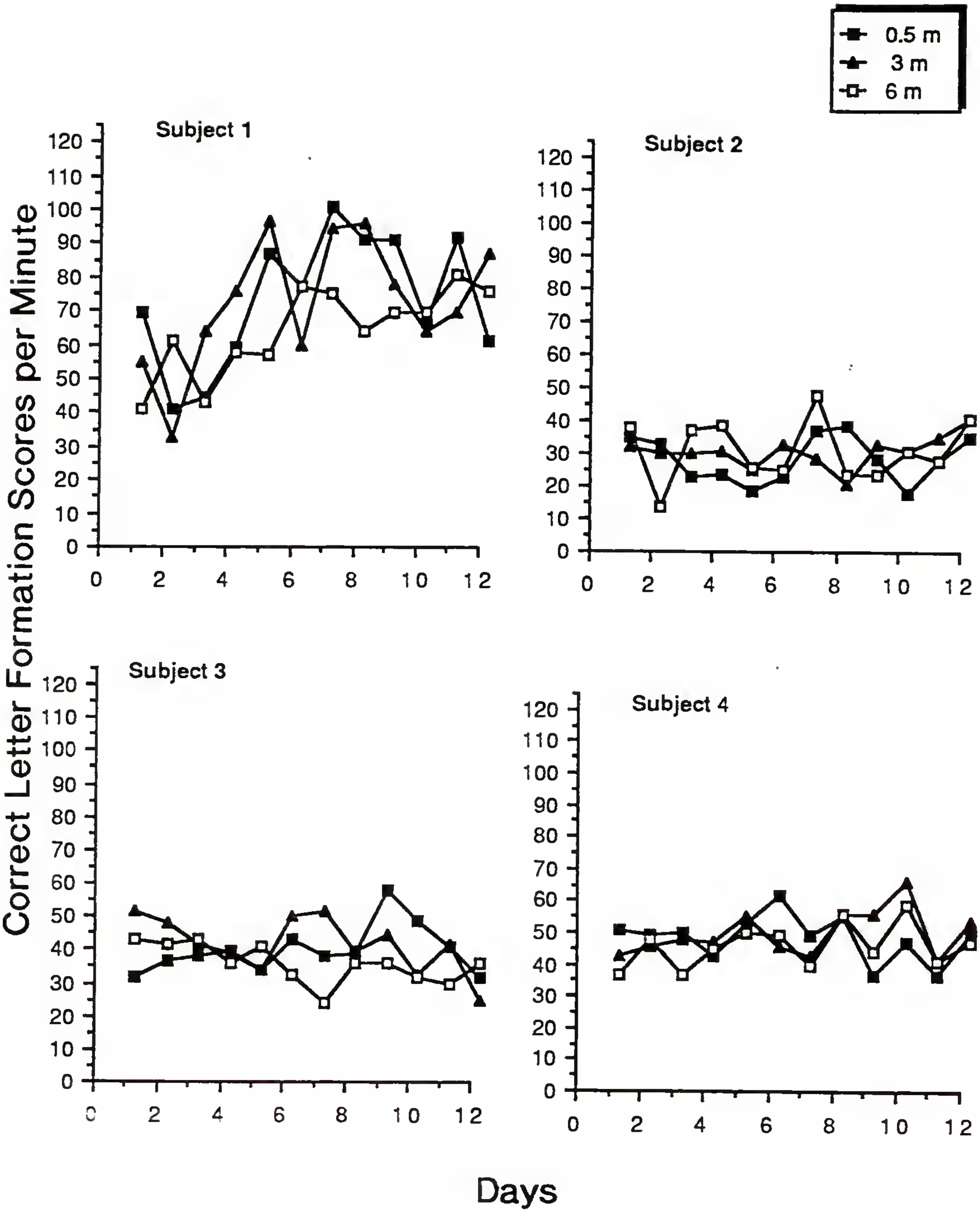


Figure 3. Lineplots for letter formation.

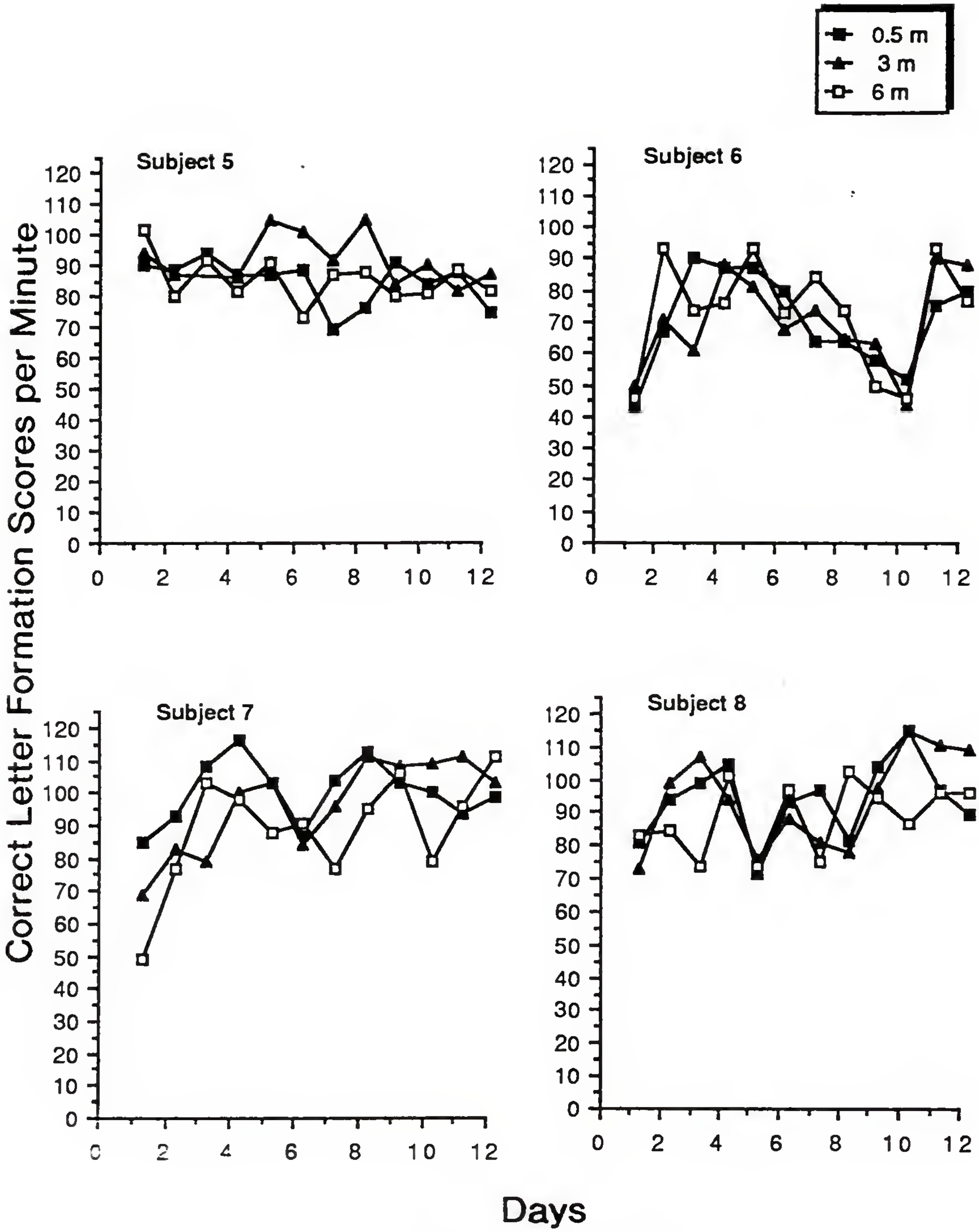


Figure 3--Continued.

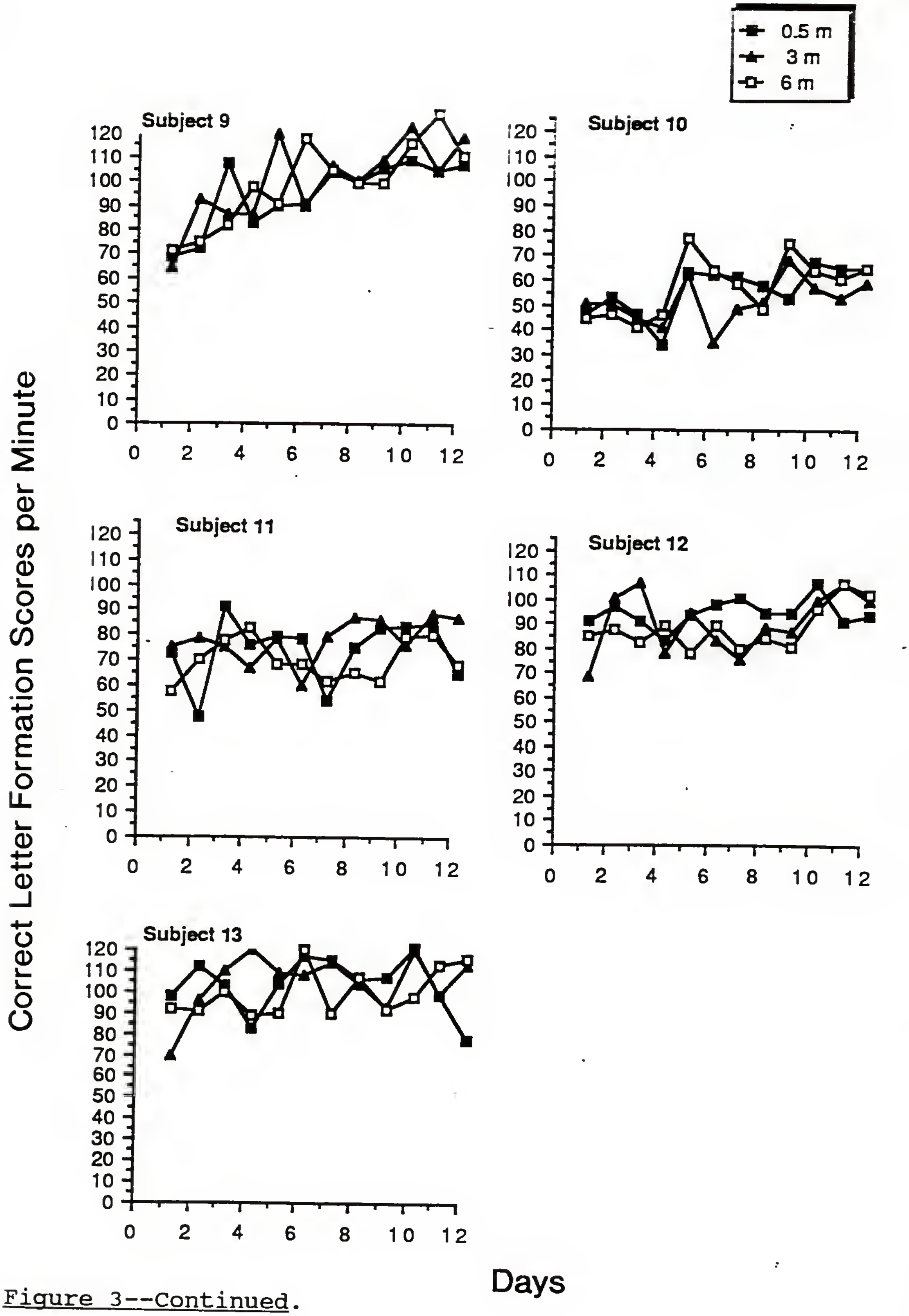
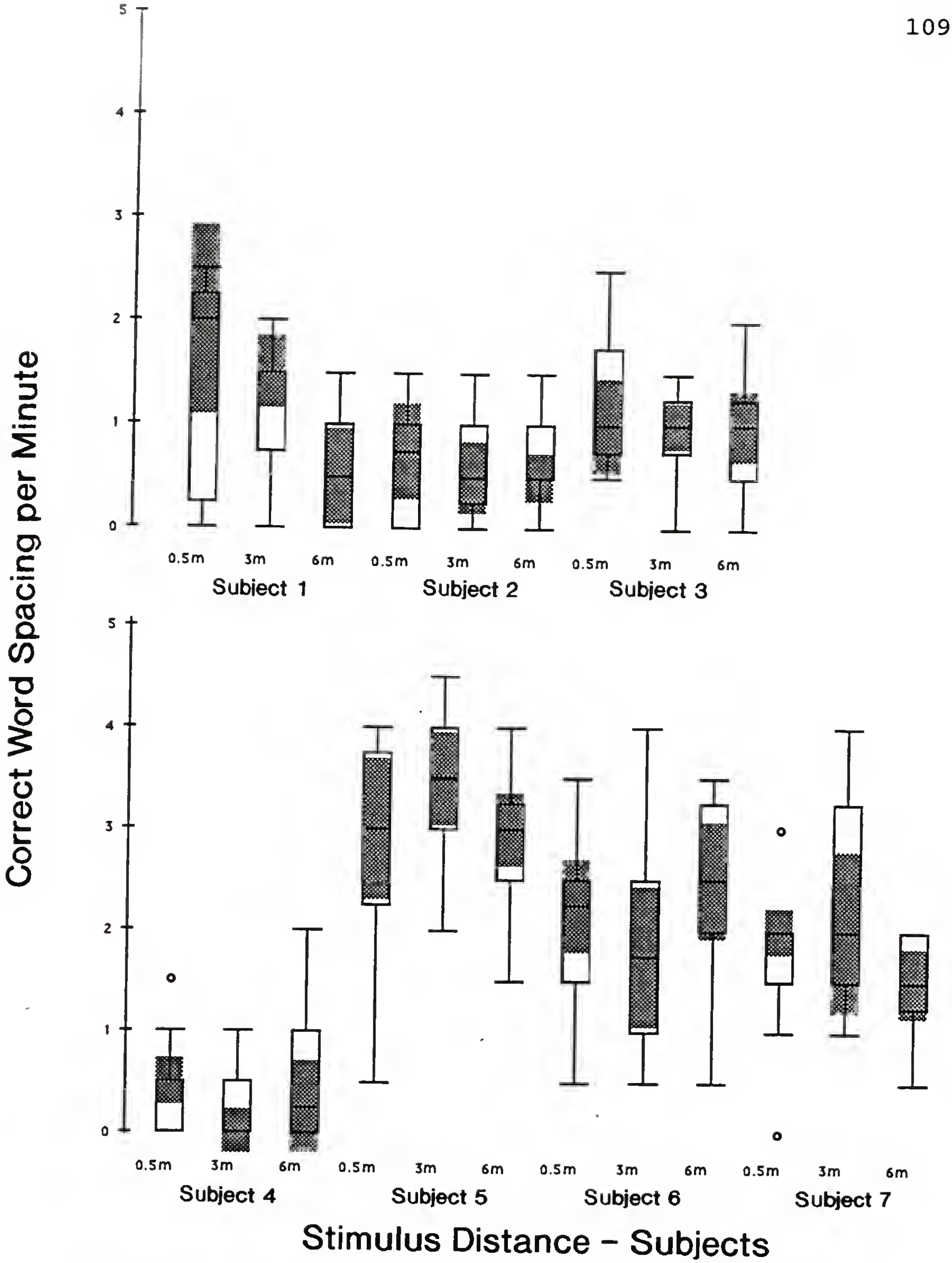
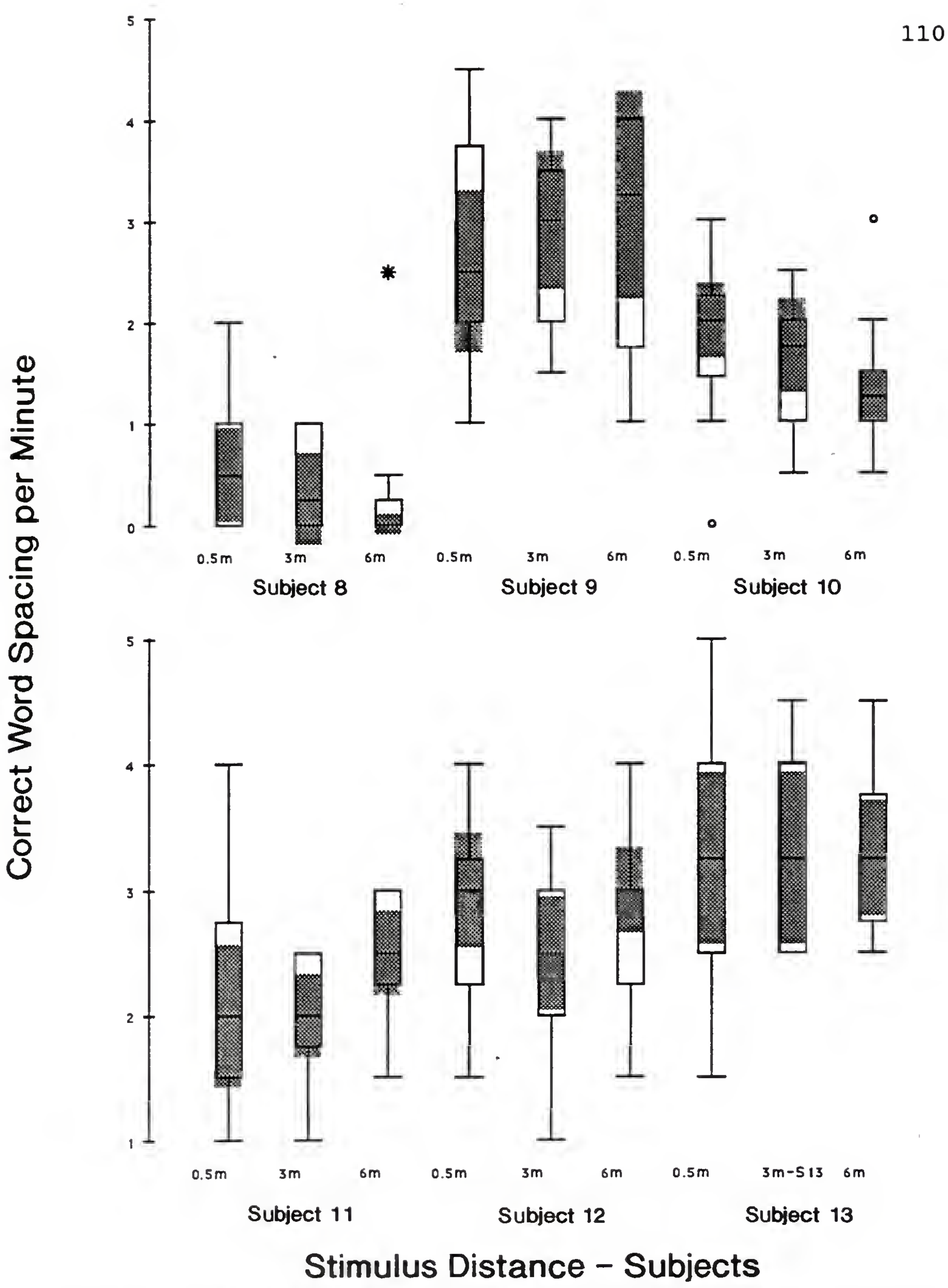


Figure 3--Continued.



Note. Maximum possible score about 10 points. Non-significance indicated when shaded areas of boxplots overlap.

Figure 4. Boxplots for word spacing.



Note. Maximum possible score about 10 points. Non-significance indicated when shaded areas of boxplots overlap.

Figure 4--Continued.

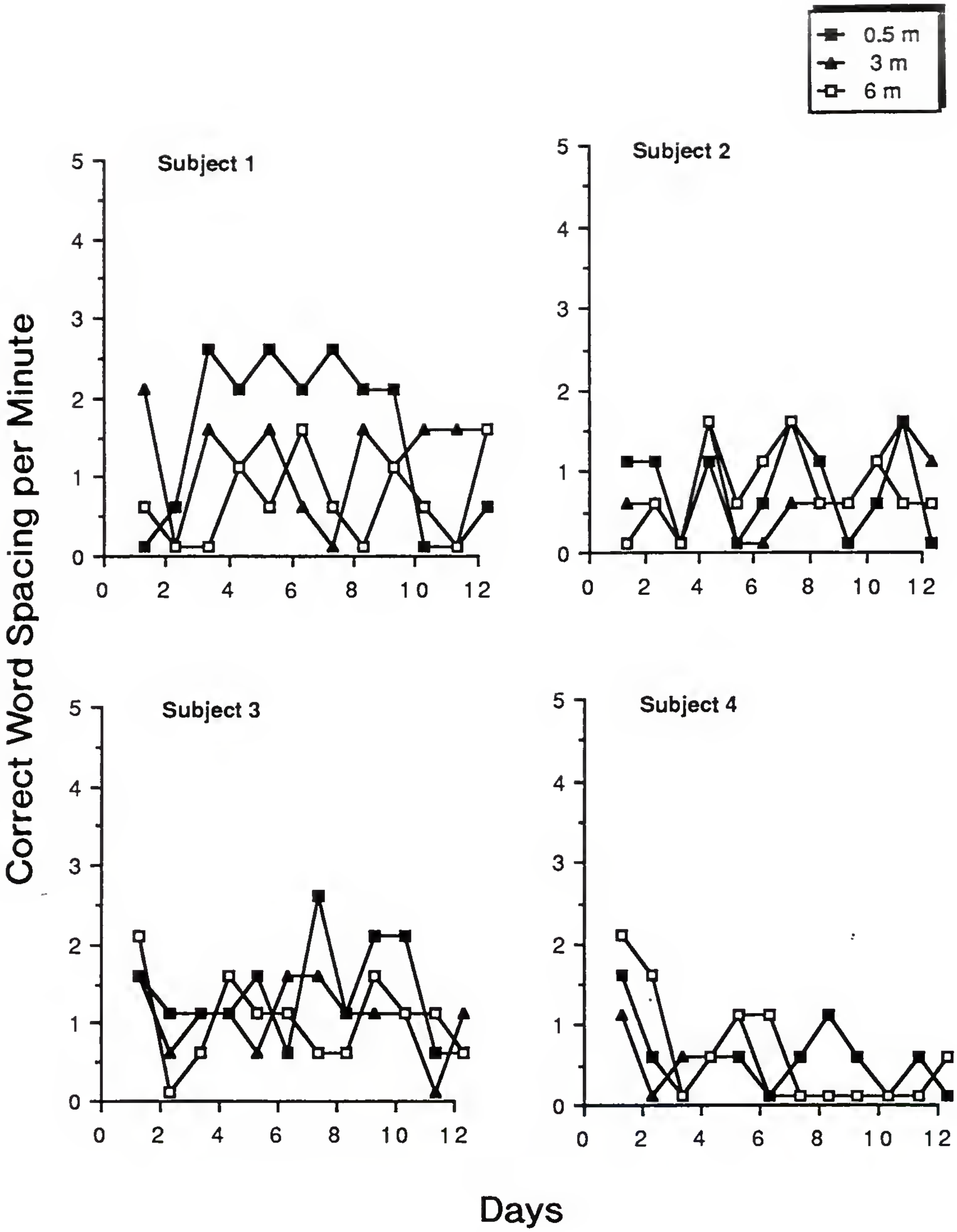


Figure 5. Lineplots for word spacing.

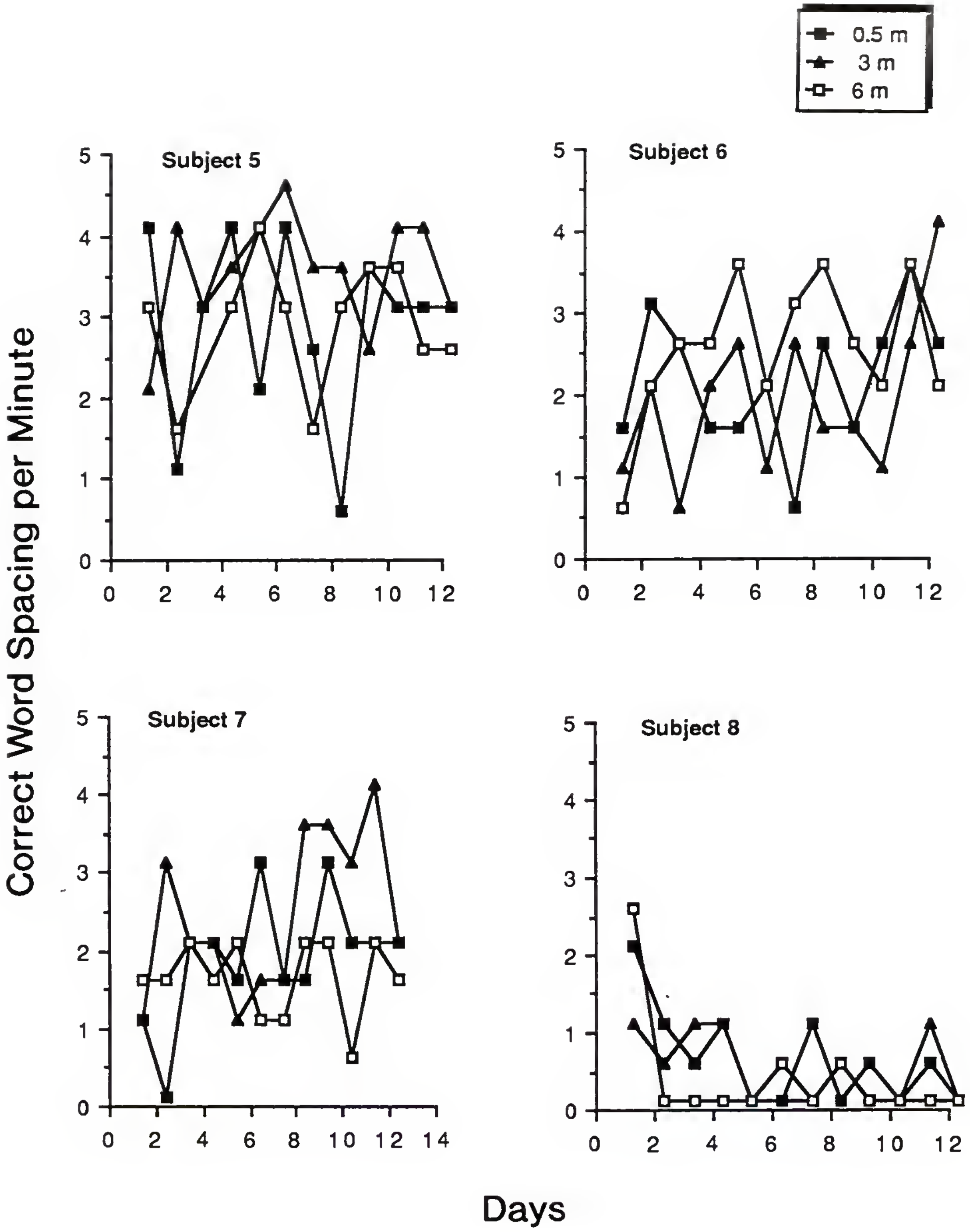


Figure 5--Continued.

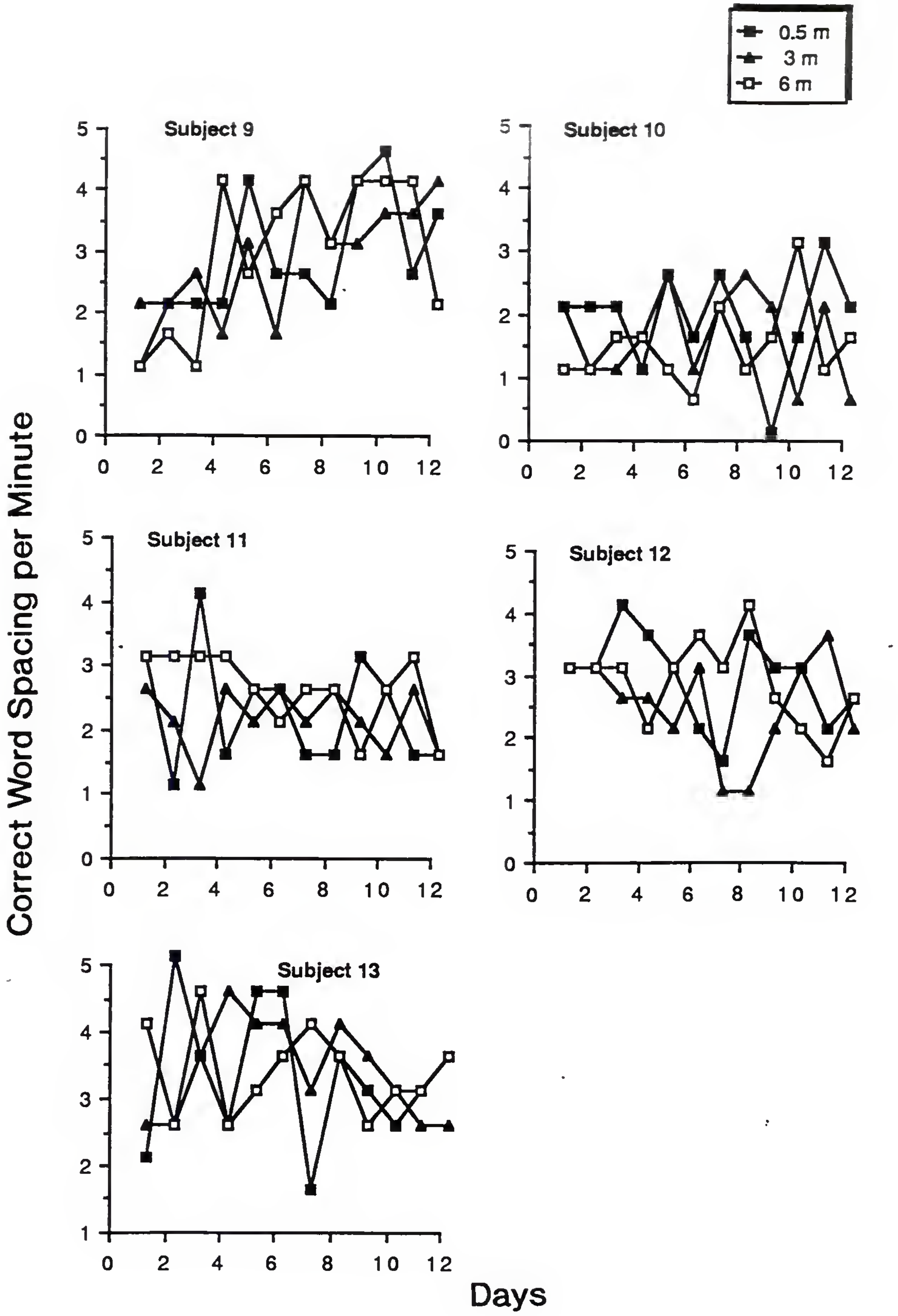


Figure 5--Continued.

Table 4

Medians and Interquartile Ranges of Letter Formation Scores for 0.5 m, 3 m, and 6 m Stimulus Distances

Subjects	Stimulus Distances 0.5m	3m	6m	0.5m	3m	6m
	Medians			InterQ Ranges		
1	70.50	70	64	31.50	32	18.50
2	25.50	28	26.50	12	3.75	14.50
3	35.50	39	33	7.75	14.25	9.50
4	46.50	44.50	43	8.50	12	9.50
5	84.50	87	81.50	11.75	15	10.50
6	68	66.50	72	25.75	24.75	35
7	98.50	98.50	90	13.75	25.50	24.25
8	92.50	93	88	18.75	29.75	19.75
9	98	99	96	22.75	29	31.25
10	56.50	47.50	56.50	16.75	13.50	18.75
11	74	75	65	16	11.75	16.50
12	90.50	88	83	6.75	20.50	13.75
13	101	104.50	91	16	17	21.25

Note. Maximum Score = 125

Table 5

Medians and Interquartile Ranges of Word Spacing Scores for 0.5 m, 3 m, and 6 m Stimulus Distances

	Stimulus Distances					
Subjects	0.5m	3m	6m	0.5m	3m	6m
	Medians			InterQ Ranges		
1	2	1.50	0.50	2.25	0.87	1
2	0.75	0.50	0.50	1	0.87	0.50
3	1	1	1	1.25	0.75	0.87
4	0.50	0	0.25	0.50	0.50	1
5	3	3.50	3	1.75	1	1
6	2.25	1.75	2.50	1	1.50	1.37
7	2	2	1.50	0.50	1.87	0.87
8	0.50	0.25	0	1	1	0.37
9	2.50	3	3.25	1.87	1.50	2.37
10	2	1.75	1.25	0.95	1	0.50
11	2	2	2.50	1.37	0.87	0.87
12	3	2.50	3	1.25	1	0.87
13	3.25	3.25	3.25	1.75	1.50	1.25

Note. Maximum Score = 5

Table 6

Intercept Coefficients (y) and Slope Coefficients (x) and t-ratios for Letter Formation Trends for 0.5 m, 3 m, and 6 m Stimulus Distances

	0.5 m			3 m			6 m		
Subject	t-ratio	y	x	t-ratio	y	x	t-ratio	y	x
1	1.63	54.36	2.48	1.71	53.40	2.54	*4.34	42.49	2.91
2	0.11	25.15	0.07	1.26	24.62	0.51	0.25	26.90	0.21
3	1.24	32.24	0.74	-2.10	47.10	-1.27	*-2.54	39.50	-1.00
4	-1.05	49.60	-0.62	1.48	41.47	0.86	1.27	38.42	0.72
5	-1.65	88.21	-0.97	-0.82	93.18	-0.60	-1.55	88.44	-0.97
6	-0.05	67.97	-0.06	0.84	60.36	1.06	-0.07	70.95	-0.11
7	0.38	95.50	0.31	*4.40	72.61	3.19	2.07	69.53	2.56
8	0.95	85.02	0.93	1.80	77.92	2.03	1.54	77.47	1.29
9	*4.03	71.38	3.11	*3.74	73.12	3.62	*5.03	68.92	4.14
10	*2.97	40.74	1.90	1.62	40.96	1.16	*2.30	41.44	2.00
11	0.62	66.42	0.68	2.07	66.40	1.31	0.51	64.30	0.36
12	0.99	88.23	0.47	1.24	78.99	1.26	*2.29	75.56	1.47
13	-0.27	101.6	-0.30	1.32	90.99	1.49	2.03	84.83	1.70

*Significant $p > 0.05$ 10 df

Table 7

Intercept Coefficients (y) and Slope Coefficients (x) and t-ratios for Word Spacing Trends for 0.5 m, 3 m, and 6 m Stimulus Distances

	0.5 m			3 m			6 m		
Subject	t-ratio	y	x	t-ratio	y	x	t-ratio	y	x
1	-0.67	1.77	-0.06	0.47	0.95	0.03	0.89	0.31	0.04
2	-0.27	0.76	-0.01	1.56	0.20	0.06	0.66	0.48	0.03
3	-0.18	1.32	-0.01	-0.78	1.51	-0.03	-0.43	1.05	-0.02
4	-1.41	0.79	-0.05	-1.64	0.62	-0.05	*-2.83	1.37	-0.13
5	-0.05	2.83	-0.01	0.60	3.22	0.04	0.34	2.65	0.02
6	0.86	1.70	0.06	1.75	0.99	0.13	1.38	1.83	0.97
7	1.85	1.05	0.11	1.90	1.38	0.15	-0.28	1.62	-0.01
8	*-2.64	1.26	-0.11	-1.63	0.80	-0.06	-1.65	0.89	-0.09
9	*2.63	1.49	0.19	*3.51	1.60	0.18	*2.25	1.59	0.20
10	-0.07	1.81	-0.00	-0.42	1.71	-0.03	1.15	0.98	0.06
11	-0.89	2.60	-0.07	-0.36	2.14	-0.02	*-2.39	3.12	-0.09
12	-1.40	3.36	-0.08	-0.53	2.61	-0.04	-1.31	3.23	-0.07
13	-0.46	3.52	-0.04	-0.53	3.51	-0.03	-0.59	3.51	-0.03

*Significant $p > 0.05$ 10 df

in boxplots (Velleman & Velleman, 1988) for letter formation in Figure 2 and word spacing in Figure 4 and are shown numerically in data summaries for letter formation in Tables 4 and 6 and word spacing in Tables 5 and 7.

In the boxplots, the boxes depict scores from the 25th percentile to the 75th percentile and the median is indicated by a horizontal line in the box. The "whiskers" of the boxplot depict the range of data. Outlier scores are indicated with a circle or, if they are far outliers, with a starburst. Shaded areas of the boxplots extend symmetrically from the median. Thus, boxplots show the overall level, variability, and symmetry of the data and any extreme data points. Several boxplots can be compared for level and variability. In addition, boxplots can be compared by observing the overlap of the central boxes. When shaded areas of two boxplots do not overlap, this indicates significant differences in the population medians at a 5% level (Velleman & Hoaglin, 1981).

Trends, or the slope of the data across time, are shown in line graphs (Figures 3 and 5) for letter formation and word spacing scores for distances 0.5 m, 3 m, and 6 m for each subject. Data trends were considered in two ways. First, for the alternating treatments design, slopes for the three distances were compared to determine data patterns for the alternating treatments. The effect of a condition is demonstrated if the path for that condition diverges from the data paths of alternating conditions. differential effects of the treatments are not established if data paths do not diverge. Data paths for the three distances are contrasted in the line graphs for letter formation shown in Figure 3 and for word spacing shown in Figure 5.

Second, the slope of the data for any one stimulus distance was determined for acceleration or deceleration trends. Subject's scores across the 12 days of the study were subjected to least squares regression analysis to determine time as a predictor of the subject's scores. The intercept coefficient of the regression line was an indication of the value of y when x = 0, or where the line intercepts the y-axis. The slope coefficient specified the steepness and sign of the regression line and was an indication of the relationship between y and x. The sign of the x coefficient was positive for acceleration trends and negative for deceleration trends. To identify significant acceleration or deceleration slopes, t-ratios were used. The t-ratio was used to determine departure of the slope from no slope as being significant at the 5% level for predicting improving or decreasing scores over time (Velleman & Velleman, 1988).

The intercept coefficients are shown as y and slope coefficients are shown as x in Table 6 for letter formation and Table 7 for word spacing. For example, in Table 6 for Subject 1, the regression line intercepted the x-axis at a score of 54.36 and the score increased 1.48 points per day. The sign of the x coefficient was positive indicating an increase in the scores across time. The t-ratio for the steepness of this increase was 1.63, a nonsignificant increase when t must exceed 2.228 at the 0.05 confidence level for 12-2 = 10 degrees of freedom.

Maximum scores for letter formation were about 125 points and for word spacing were about 5 points. the maximum possible points varied since they were determined by the number of letters and words a subject was able to complete in each 2-minute time period.

Question 1

The question will be stated and then the data regarding the level, variability, and trend will be presented. Tables 4 and 6 and Figures 2 and 3 will be used in this discussion.

1. What are the effects on the level, variability, and trend of letter formation scores with copying stimuli placed at 0.5 m, 3 m, and 6 m distances from the subject?

Level

As shown in Table 4, the median scores for letter formation were from 25.5 to 104.5 across the 13 subjects. For each subject, the median scores were similar across the three stimulus distances.

Variability

Interquartile ranges (Table 4) were from 3.75 points to 31.25. For each subject, the ranges were similar across the three stimulus distances and no one stimulus distance was significantly different from another (Figure 2).

Trend

Visual inspection of the data paths for the three stimulus distances showed that (Figure 3) data slopes did not diverge. In the regression analysis (Table 6) significant trends at the 5% level were found in letter formation scores across time for Subject 9 at all three stimulus distances, for Subject 10 at the 0.5 m distance, for Subject 7 at the 3 m distance, and for Subjects 1, 3, 10, and 12 at the 6 m distance. Of the nine significant trends, eight (88%) of these were acceleration trends and one was a deceleration trend. The eight significant acceleration trends accounted for 20.5% of the total number of 39 trends, a percentage that exceeds what would be expected by chance occurrence of acceleration trends. However data paths showing consistent, optimal performance at any one stimulus distance did not emerge.

Summary

In summary, considering that the maximum possible letter formation score for each sample was about 125 points, the level of scores revealed some difficulty with handwriting, especially for Subjects 2, 3, and 4. Within subject variability was not significantly different for any subject (Figure 2). Data paths did not diverge to indicate a preferred stimulus distance for optimal performance for any of the subjects (Figure 3). From the acceleration data, there were increases in letter formation scores with repeated exposures to the task for some children at some stimulus distances.

Question 2

The question will be stated and then the data regarding the level, variability, and trend will be presented. For this discussion, Tables 5 and 7 and Figures 4 and 5 will be used.

2. What are the effects on the level, variability, and trend of word spacing scores with copying stimuli placed at 0.5 m, 3 m, and 6 m distances from the subject?

Level

Median scores were from 0 to 3.5 (Table 5). Within each subject, median scores were similar across the three stimulus distances. Exceptions to this were significant differences for Subject 1, 4, and 10. For Subject 1, median scores at the 6 m distance were lower than median scores at the 0.5 m and 3 m distances. For Subject 4, median scores at the 3 m distance were lower than at the 0.5 m distance. For Subject 10, median scores at the 6 m distance were lower than at the 0.5 m distance.

Variability

Interquartile ranges were from 0.37 to 2.37 (Table 5). As shown in Figure 4, for within subjects the interquartile ranges were significantly lower for the 6 m distance as compared to the 0.5 m and 3 m distances in Subject 1; for the 3 m distance as compared to the 0.5 m distance in Subject 4; and for the 6 m distance as compared to the 0.5 m distance in Subject 10.

Trend

Inspection of the line charts (figure 5) shows that, for the three stimulus distances, no one data path clearly diverged from the other data paths for any subject. The results of the regression analysis (Table 7) revealed that the data slopes were not significant for most stimulus distances. There were six significant trends, with acceleration trends for all three stimulus distances in Subject 9, deceleration trends for Subject 8 at the 0.5 m distance and for Subjects 4 and 11 at the 6 m stimulus distance. Of the 39 total trends, 15% were significant, an amount that somewhat exceeded what would be expected by chance occurrence of significant trends. However, acceleration and deceleration trends were equal. Thus, data trends for no one stimulus distance emerged as being consistent with higher or lower scores than the data trends for the other stimulus distances.

Summary

In summary, considering that the maximum possible word spacing score was about 5 points, the level of the subjects' scores reveals some difficulty with word spacing especially for Subjects 2, 4, and 8. Within subject differences were observed in three subjects with higher median scores for the 0.5 m stimulus distance in 3 subjects. Data paths for the three distances showed no clear deviation of scores for any one stimulus distance in any of the subjects. The number of significant acceleration and deceleration trends were equal in number.

Summary

The purpose of this investigation was to address the effects of stimulus distance on handwriting performance during a copying task. Two research questions were posed to address the effects on level, variability, and trend of letter formation and word spacing scores when the copying stimulus was placed in front of the subject at three distances: 0.5 m, 3 m, and 6 m. This investigation was replicated for 13 single subjects. Data from each subject were analyzed for level (medians), variability (interquartile ranges), and trend (slope) through visual inspection of boxplots and line graphs and through regression analysis.

The level of the scores for letter formation was not different across the three stimulus distances for any subject. For word spacing, the level of the scores was higher for the 0.5 m distance in three subjects. The variability of the letter formation and word spacing scores was not different across the three stimulus distances for any subject. Of the significant trends observed, the majority were acceleration for letter formation and equal in number to deceleration trends for word spacing. When data trends were compared for the three stimulus distances, no clear divergence of a data path for any one stimulus distance was observed in any subject.

In summary, investigation of level, variability, and trend of letter formation and word spacing data did not identify 0.5 m, 3 m, or 6 m stimulus distance as being optimal for enhancing handwriting legibility in second grade boys. In Chapter V, implications of these findings will be discussed.

CHAPTER V
DISCUSSION

Introduction

This chapter contains four major sections. In section one, the purpose of the study, literature review, and methods will be summarized. In section two, the research questions will be reviewed and conclusions regarding each one will be described. In the third section, the findings, problems and limitations, and the practical implications of the findings will be discussed. In the fourth section, future research considerations will be suggested.

Review of Purpose, Literature, and Methods

Review of Purpose

The purpose of this study was to investigate the effects of three distances of handwriting stimuli on handwriting legibility of second grade children with handwriting difficulties. Copying from the chalkboard or from materials at the desk is an everyday occurrence in handwriting instruction. Copying tasks demand highly complex visual, motor, and attention abilities. Yet, there is a paucity of information about optimal factors for copying tasks. It is believed that optimizing copying tasks could enhance handwriting instruction, especially for children at-risk for developing handwriting problems. In this study, the distance of the stimulus from the child was posed as one factor that could affect handwriting performance during copying tasks.

Review of the Literature

Handwriting literature was found in diverse fields of education, psychology, neuroscience, and physical sciences. For the purposes of this study, professional literature was reviewed regarding neuropsychological processes for handwriting and handwriting evaluation and instruction. Literature included a neuropsychological model of handwriting; motor, visual, and attentional aspects of the handwriting process; handwriting assessment and handwriting instruction.

A neuropsychological model of handwriting depicted graphomotor skills as a visible form of language involving combined motoric, visual-spatial, and linguistic systems. Such a model was useful for illustrating possible processes involved in seeing, hearing, or thinking and then writing a word or for describing graphomotor problems.

Motor aspects of graphomotor skills were considered in terms of findings from animal and human neurocellular studies of primary motor, supplementary motor, and premotor cortex functions. In psychophysical studies of handwriting, the velocity, acceleration, force, speed, and reaction time of movements were precisely measured. The role of hand grip, muscle strength and dexterity, and body posture were described as ergonomic aspects of handwriting.

Visual aspects of graphomotor skills included visual acuity, eye movements, and depth perception requisites. The contributions of attentional mechanisms in the brain stem arousal system, the frontal lobes, and the inferior parietal lobule were described.

Evaluation of handwritten products typically addressed spacing, letter form, alignment, slant, and line quality. Handwriting evaluation instruments were found to have limitations in psychometric properties and usability.

Handwriting instruction concerns included developmental aspects; modeling; manuscript versus cursive; Palmer, Zaner-Bloser, and D'Nealian methods; legibility; rate; and computer versus handwritten output. Single subject studies of handwriting instruction reported improvements in handwriting. Methods included self-assessment, self-instruction, modeling, and practice. Generalization to other settings and to letters for which intervention had not been provided was observed in some studies and not in others.

In summary, a review of the extensive handwriting literature provided relevant and useful information for considering handwriting in school children. However, the instructional issue addressed in this study, namely, stimulus distance during copying tasks, was not found in the literature.

Review of the Methods

In this study, the subjects included 13 second grade boys with handwriting difficulties. Three subjects were receiving resource room services for part of each day due to an emotional handicap. Four subjects were receiving services for part of each day for children determined to be at-risk for learning problems and who had low achievement test scores. Six subjects were not receiving any special services except for one child who received enrichment program support for gifted children. All children had been identified by the classroom or varying exceptionalities teachers as having handwriting difficulties. The settings were the school library and school cafeteria stage in a public elementary school. These settings were used at quiet times when other activities were not scheduled.

Personnel included four research assistants, three rating assistants, and the investigator. The research assistants administered the handwriting tasks to the subjects. The three rating assistants participated in reliability assessments of the instrument and rating of the handwriting samples.

The dependent variable was a criterion-based handwriting checklist, Error Analysis of Children's Handwriting (EACH) devised for the study. This instrument was used to rate letter formation according to five criteria and to assess word spacing. Interrater agreements of at least 80% were achieved prior to rating of the samples and during the rating process (see Table 2).

The independent variable consisted of nine, 50-letter sentences composed of nonwords devised by the investigator. The model sentences were handwritten with black ink on primary-lined, white paper the size of regular paper (20 x 27 cm.) and the size of a chalkboard (1.5 meter x 1 meter). The paper was placed upright, on easels centered in front of the subject. In each session, three different sentences were presented, one at each stimulus distance of 0.5, 3, and 6 meters. Stimulus distance was measured from the front edge of the easel to the edge of the table next to the child's torso. The regular-sized paper was used for the stimulus at the 0.5 meter distance and the chalkboard-sized paper was used at the 3 and 6 meter distances. Subjects were timed for 2 minutes while copying each stimulus sentence. Subjects wrote with ordinary number two pencils on primary-lined paper. The daily handwriting sample for each child included three different sentences copied from model sentences placed at the three distance conditions. During the study, the identity of the child and the stimulus distance were not disclosed to the investigator and rating assistant.

An alternating treatments design was used to compare the effects of three stimulus distance conditions on letter formation and word spacing. From day to day, distance conditions were alternated within sessions and each distance condition was implemented once each day. The three stimulus distance conditions were counterbalanced for a total of six seating orders. The six seating orders were counterbalanced across the nine sentences and the 12 days of the study.

The methods for investigating the effects of three stimulus distances upon handwriting legibility have been reviewed. These methods were designed to address the research questions presented in the next section.

Review of the Questions and Results

In this section the two research questions will be reviewed. Letter formation and word spacing data level, variability and trend will be summarized. Conclusions will be stated.

In the first question, the effects on the level, variability, and trends of letter formation scores with copying stimuli at 0.5 m, 3 m, and 6 m stimulus distances were addressed. The findings were that there were no differences in the level or variability of the scores within subjects for the three stimulus distances. Of the total significant trends for all subjects, there were more acceleration than deceleration trends. None of the data paths for the three distances diverged to show one stimulus distance as being advantageous for letter formation scores for any subject.

In the second question, the effects on the level, variability, and trends of letter formation scores with copying stimuli at 0.5 m, 3 m, and 6 m distances were addressed. The results were that there were no differences in the level or variability of the scores within subjects except that scores at the 0.5 distance were significantly higher than the scores at other distances in three subjects. Significant acceleration and deceleration trends were about equal. None of the data paths for the three distances diverged to show one stimulus distance as being advantageous for letter formation scores for any subject.

From these findings it was concluded that level, variability, and trend of letter formation and word spacing scores were not affected by the stimulus distance. No consistent pattern of performance emerged as being preferable for, or deleterious to, letter formation and word spacing with copying stimuli placed at 0.5 m, 3 m, or 6 m from the subject.

Discussion and Implications

In this section, the interpretation and literature support will be summarized. Second, the problems and limitations of the study will be stated. Finally, practical implications of the findings for the classroom will be presented.

Summary of Findings, Interpretation, and Literature Support

Summary of Findings

The analysis of the data relative to the principle objectives of the study indicated that level, variability, and trend of letter formation and word spacing scores were not differentially affected by stimulus distances of 0.5 m, 3 m, and 6 m. Thus, for a sentence copying task, handwriting legibility, as measured by letter formation and word spacing, was not affected by the distance of the stimulus from the child.

Levels of the scores showed that the subjects had difficulty with letter formation and word spacing at all three stimuli distances. For any given stimulus distance, there was intrasubject variability: a subject would do well at one distance one day and poor at that distance another day. However, subjects tended to score at a high or low level across the days of the study regardless of the stimulus distance. That is, subjects who scored in the 30's tended to score in the 30's across the three distances and subjects who scored in the 100's tended to score in the 100's across the three distances. Thus, there tended to be less variability in intersubject ranges than intrasubject ranges. Celeration trends revealed a limited number of significant acceleration trends in letter formation indicating that at some distances some subjects tended to improve with repeated practice of the copying task. However, similar acceleration trends were not found in word spacing.

Letter formation scores were reviewed across subject types. Subjects 1-3 were receiving pull-out services for an emotionally handicapping condition. Subjects 2 and 3 had low letter formation scores compared to Subjects 5-13. Subject 1 wore glasses to correct a visual refractive error but his scores were not as low as his classmates. Of the four subjects who were receiving services for low academic achievement, Subject 4 had lower letter formation scores than Subjects 5-13. Subject 4 also exhibited eye squinting when looking at a stimulus and had uncorrected visual acuity of 20/100 on the school vision screening that would place him as a "partially seeing" child (Hathaway, 1959). In Subjects 8-13 who were not receiving any special services, five of these subjects had the highest letter formation scores. The subject with the highest scores of any subject in the study was the child who was in the program for the gifted.

Owing to the restricted range of possible scores for word spacing, the identification of trends for subject types were limited to two observations. First, the lowest median scores for word spacing of any children in the study were made by Subjects 4 and 8. Subject 4 was in the program for low academic achievement and had uncorrected visual acuity problems and Subject 8 was not receiving any services. Second, highest median scores for word spacing of any child in the study were made by the subject who was in a program for gifted children.

Subject 9 showed significant acceleration trends for letter formation and word spacing across all three stimulus distances. He was the single example of improved performance with repeated exposure to the task at all three stimulus distances.

Interpretation

The data that were analyzed allowed the writer to conclude that stimulus distance is not a major variable in handwriting legibility as determined by letter formation and word spacing. Further, these findings are thought to be due to the intrasubject and intersubject variability that was observed. Individual subjects' performances were variable from one day to another for any given stimulus distance and no one stimulus distance appeared to differentially affect handwriting legibility. Therefore, stimulus distance was not identified as a major influence on handwriting legibility.

Variability in an individual's handwriting is thought to be task-dependent, motivation-related, and a reflection of central nervous system motor, visual, and attentional processes. For purposes of this research study, an attempt was made to carefully control the task variables and to enhance subjects' motivation through the use of frequent reinforcers. According to the subjects' health histories, visual acuity, depth perception, and oculomotor control were assumed to be normal. In addition, all subjects had at least one year of daily, formal handwriting instruction. In the Error Analysis of Children's Handwriting scoring system, subjects were not penalized for individualistic handwriting style but rather for conformity to legible letter form and word spacing.

It is proposed that the variability in the subjects' performance at the three distances reflects individual differences in motor, visual, and attentional processes. This proposal is based upon several observations of the types of errors that the subjects made.

Motor performance difficulties were seen in some subjects' slow rates of responding and tremorous lines. Low letter formation scores were due primarily to slowness in handwriting and completing only a few words of the stimulus sentence. The child knew the correct letter forms but had difficulty producing the letters at an efficient rate. In addition, the line quality of some subjects was wavy and tremorous, indicating difficulty with motor control.

Visual difficulties were thought to be related to low scores that were due to malalignment of letters in relationship to the lines or to malorientation of the letters. These problems indicate difficulty, not with the correct form of the letter, but with visualizing how the letter should be placed in a spatial relationship to other letters or words or to the lines on the page.

Attentional problems may have been involved when the subject's performance deteriorated from the first to the last part of a sentence or from the first to the last sentence within one session. Problems in alternating attention between the stimulus and the writing paper were thought to be involved when the subject would omit sections of a sentence. When haphazard, rushed, careless writing alternated with orderly, slow, and careful writing in the same subject, the performance was interpreted as being related to attentional processes.

In summary, it is proposed that subjects in this study were presented with a copying task in a consistent manner and on a highly motivating reinforcement schedule. The variability of their performance from one day to the next at any given stimulus distance is thought to be related, not to stimulus distance, but to possible unknown motor, visual, and attentional processes that relate to handwriting performance. Children who have existing problems such as an emotionally handicapping condition or uncorrected visual acuity difficulties, may be at-risk for letter formation and word spacing illegibilities.

Literature Support

In the handwriting literature, the complexity of copying tasks was identified. Copying was analyzed as a highly skilled task requiring motor, visual, and attentional functions.

Motor requisites include activity of motor systems for a number of functions. Fractionation of finger movements and variations in movement force, velocity, and acceleration are required to manipulate a writing tool. Motor planning of purposive motor movements involve visual and somatosensory guidance of movements. Anticipatory postural responses are needed to assume the writing posture. Stability of the trunk and shoulder are required for refined distal movement. Adequate grasp and eye-hand coordination are developmental motor prerequisites for handwriting in children.

Visual requisites included four basic functions. The visual cortex is involved in the visualization of the movement needed to form the grapheme. Adequate visual acuity is needed in order to see the stimulus to be copied. Eye movements enable the eye to aim alternately between the model to be copied and the hand. Depth perception allows focusing upon stimuli presented at various distances from the subject.

Attentional mechanisms include activity of the midbrain reticular formation so that the cortex is sufficiently aroused to process and interpret incoming sensory stimuli. Activity of the parietal cortex insures attention to stimuli that are significant to the organism. Frontal lobe functions are needed for attention to the task and for planning and initiating what needs to be done in order to complete the task at hand. In a handwriting copying task, motor, visual, and attentional requisites are coordinated with linguistic cortices.

Considering the complexity of handwriting copying tasks, the distance of the stimulus to be copied was posed by this investigator as a possible factor in copying performance. It was proposed that, as the distance from the stimulus increased, the motor, visual, and attentional demands of the copying task also increased. For the child with handwriting problems, performance could deteriorate because of difficulty composing the motor movement needed to produce the letter or problems retaining the visual image of the model or screening out competing stimuli.

The investigator also acknowledged that distance from the stimulus may have little effect upon copying performance and that other factors need to be considered. The results of this study point to the latter posit. Handwriting copying tasks are very complex tasks. Motor, visual, attentional, and unknown factors other than stimulus distance affect copying performance.

Problems and Limitations

There were problems and limitations that were encountered in the process of implementing this study that should be considered when interpreting these data. At the outset of this study, the intention was to use stimuli written on a chalkboard for the 3 m and 6 m distances. This procedure would have represented the classroom environment where chalkboards are used on a daily basis.

However, for practical reasons, chalkboard replicas were devised to use for the 3 m and 6 m distances. Another advantage to this alternative was that, except for size, the stimuli for the 3 m and 6 m distances were identical to the stimuli for the 0.5 m distance. For the chalkboard replicas, the stimulus sentences were each written in black ink on a sheet of white paper that was the size of a chalkboard. The sentence sheets were ring-bound into a large tablet for ease in presenting the desired sentence.

The contrast and line quality of stimuli written with black ink marker on white paper was superior to stimuli written on with chalk on a chalkboard. It is possible that copying performance in response to 3 m and 6 m distances may have been different if chalkboards had been used.

The results of this investigation have implications for the classroom. Findings can also be applied to the development of models for describing motor behavior.

Classroom

Three implications for the classroom were identified. First, as seen in the results of this investigation, no one stimulus distance resulted in higher rates of correct letter formation or word spacing. Based upon the findings in this study, classroom seating location in relationship to the chalkboard is not a major factor to consider in handwriting instruction. For children such as Subject 4 who showed uncorrected visual acuity problems, stimulus distance may be less of a concern than measures to correct the acuity problems.

A second implication for the classroom is that Subject 9 improved in handwriting performance of letter form and word spacing with 6 minutes of practice per day for a period of 12 days. Thus, when handwriting tasks are specified and administered in a systematic way, performance can improves with a few minutes of practice per day in a few days time for some subjects.

Finally, Subjects 1, 2, and 3 who were receiving services for an emotionally handicapping condition attained the lowest letter formation scores. The low scores were due primarily to their slow handwriting speed rather than to inadequate letter form. These subjects showed improvement over time and Subject 3 showed improvement with stimuli at the 0.5 m distance and not the 3 m and 6 m distances. For some children, handwriting efficiency, not letter form, will need to be emphasized in instruction. There will be some children who may make the best progress with stimuli placed at the desk for handwriting copying tasks.

Neuropsychological Model

In the neuropsychological model (Figure 1) presented in Chapter II of this study, the task of copying visual stimuli was presented as a visual-language-motor process. The subject sees the visual stimulus to be copied and the visual system analyzes the visual features of the stimulus. This analysis is then addressed by the graphemic lexicon or the phoneme-grapheme conversion system. In the graphemic lexicon, visual word images and spellings of words used in writing are stored. The lexicon is developed through the learning process. When the graphemic lexicon is active, a series of graphemes are released in a prescribed sequence to the graphemic motor area where the visuokinetic motor engrams for the graphemes are stored. The graphemic output motor programming area stores allographs, or various representations of individual letters, and programs for the stroke sequences needed to produce individual letters. Finally, motor programming processes include the selection of muscles, timing of movements, and neuromuscular coordination for graphic production and the word is expressed through the motor act of writing.

As an alternative to the graphemic lexicon, in the phoneme-grapheme system, words are broken down into individual phonemes and converted to letters. This phoneme-grapheme system then impacts the graphemic motor area and the motor act of writing occurs as noted above. The phoneme-grapheme conversion system is useful for spelling nonwords.

The stimuli used in this investigation were nonwords, presented in the visual form. Subjects most likely used the phoneme-grapheme conversion system to copy the nonword sentences. For those subjects who showed improvement in their performance over time it is proposed that they may have begun to establish a non-word vocabulary in their graphemic lexicons due to repeated practice with nonwords.

Suggestions for Further Research

Future research is suggested in three areas: subject variables, stimuli variables, and further analysis of the data from this study. These suggestions will be presented and general recommendations for handwriting research will be summarized.

Subjects

The within-subject variability found in this study indicate a lack of stability in subjects' handwriting performance from day to day. The extent of within-subject variability in the natural classroom environment is not known. In a future study, assessment of handwriting performance in everyday classroom handwriting tasks across several days could help to establish baseline information on within-subject variability of handwriting performance.

Future study could address the effect of subject's state and response to the task on handwriting performance. Anecdotal information regarding the subject's activity level, fatigue, motivation and compliance could be observed within and across sessions. Subjects' responses to the use of non-word stimuli versus real-word stimuli could be noted. This descriptive information could be compared to subjects' best and worst handwriting performance to examine the effect of state on handwriting performance.

Stimuli

In this study, non-word stimuli were used in attempt to control for subject's language abilities and experience. According to the neuropsychological model for graphomotor skills presented in this study, the use of non-words was believed to require that subjects process non-word stimuli by using their phoneme-grapheme system since they did not have a vocabulary of non-words established in their graphemic lexicon. In the future, the effects of non-word stimuli could be compared to the use of real words on handwriting performance. The use of real words would allow subjects to access both the graphemic lexicon and phoneme grapheme systems. In addition, the use of real words is more exemplary of the natural classroom setting. Such an investigation could provide a comparison of subject's use of dual versus singular systems for processing graphomotor responses. In addition, information on subjects' development of non-word vocabularies could be examined.

In this study, stimulus distance did not appear to be a major factor for stimuli written in black ink on white paper. The resemblance of this stimulus to the chalkboard was not determined. In future research, parameters of stimuli written on the chalkboard as compared to stimuli written on paper bear further investigation. Such a study would illuminate stimulus parameters in the use of the chalkboard which is so pervasive in classroom instruction.

For the purposes of this study, the stimuli to be copied were placed in front of the subject by the investigator. In a future study, self-placement of the material to be copied could be investigated. Preferred stimulus distance when subjects were allowed free choice of placement of the stimulus could be observed.

Follow-Up Analysis

Further analysis of extant data from this study could address letter reversals and handwriting rate. Letter reversals are commonly seen in young children who are developing handwriting skills and in children with academic problems (Mercer, 1987). Handwriting performance of subjects in this study could be examined for letter reversals and could be compared to handwriting letter formation scores and word spacing scores.

In this study, handwriting rate was used since it is thought to be a sensitive measure of performance (Tawney & Gast, 1984) for considering both accuracy and speed. Where accuracy is the primary concern, percentage correct may be used. Through further analysis of existing data in this study, the percentage correct as a measurement of handwriting accuracy could be examined and compared to rate, a measurement of handwriting speed and accuracy.

General Recommendations

General recommendations from this study for future handwriting research are twofold. First, there is a need for sampling handwriting across time. Second, there is a need for instructional-related research.

In most studies of handwriting, one-time samples of handwriting are obtained. As shown in this study, handwriting varies within an individual from day to day. Therefore, findings based upon data collected at one point in time may not be representative samplings of subjects' handwriting. For future research of handwriting performance, sampling of subjects' handwriting on more than one occurrence is recommended.

Although handwriting has been taught for many years, there is limited specific instructional-based research to help teachers determine ideal conditions, stimulus control, requisite student behaviors, or practical evaluation of handwriting instruction. Additional specific studies are needed to help teachers become more effective and efficient instructors of the legible handwriting that is important to a student's academic achievement and later occupational role performance.

APPENDIX A
ERROR ANALYSIS OF CHILDREN'S HANDWRITING (EACH)

Error Analysis of Children's Handwriting (EACH)

Subject number____ Sample Number:______ Date:______ a b c d e f g h i j k l m n o p q r s t u v w x y z

A. LETTER FORMATION ERRORS:

1. Letter is reversed, inverted or rotated

2. Letter is incomplete or left open > 1mm.

3. Letter is complete but finished in the wrong place

4. Letter has crumpled curves, irregular, jagged lines, bent strokes, deflated loops or appears tremorous.

5. Letter is > 1 mm. from relevant line.

Total

C. WORD SPACING

Space after word is less than 1/4" or more than 1/2"

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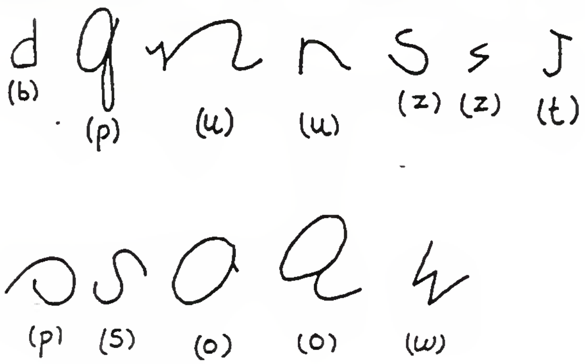
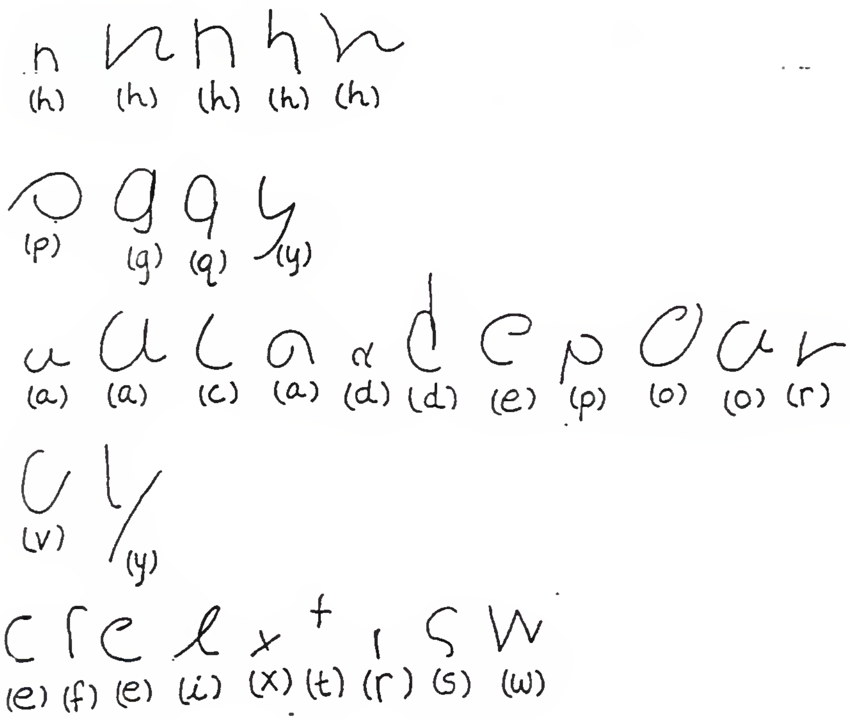
ERROR ANALYSIS OF CHILDREN'S HANDWRITING

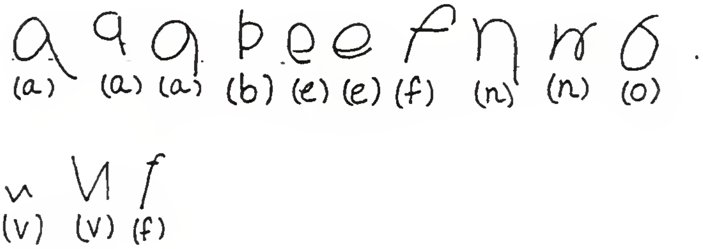
Letter is reversed, inverted or rotated:



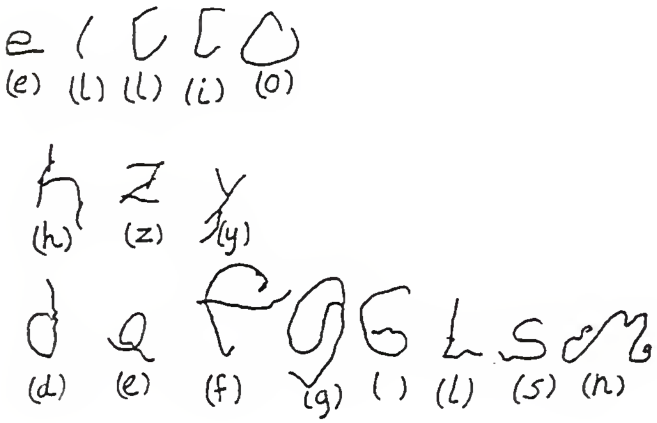
Letter is incomplete or left open > 1 mm.



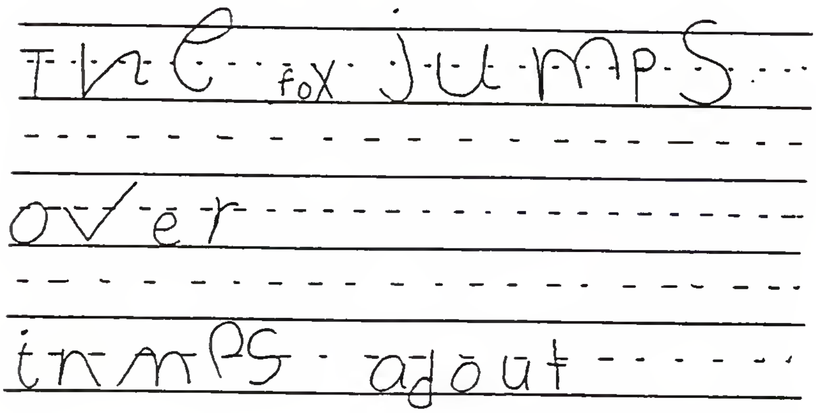
Letter is complete but finished in the wrong place.


(a) (a) (a) (b) (e) (e) (f) (n) (n) (o)
(v) (v) (f)

Letter has crumpled curves, irregular, jagged lines, bent strokes, deflated loops or appears tremorous.


(e) (l) (l) (i) (o)
(h) (z) (y)
(d) (e) (f) (g) ( ) (l) (s) (n)

Letter is > 1 mm. from relevant line.



APPENDIX B
STIMULI FOR COPYING

Ry heg z drick bappy
sived tade hirst phy
tilk gery bext tost.

Jrick yoing piked
qire ras tirst kalk
h de owey sery
bown tirl.

Yond n tind gack qo
reg jight zlew rolor
sost nake toods blimb.

Jid dy ewey j rappy
kiked dound tery hond zrick
oyes bery sere.

Kring iver gome dat
t po gorm zalk rall
hent suess qunch
yaked.

R hice rad af jlace
darm dirl rongs
zoman yity hoth
doad doods.

Tike r kound qe
tence pob shyme
tatch pwim jing
sull apen bave.

Ub jace yog rean
zoth sery qlace rown
g rilk ghich ghite shile.

Gade jas pive khile
epen qloor joof nrain
pe ipen dond shried g.

Lists of Nonwords

A. Background

Frequently illegible letters (or reversed letters);
- Consonants most frequently illegible:
  - b, d, g, h, j, n, p, r, s, t
- Consonants frequently illegible but also occurring least frequently as initial consonants:
  - k, q, y, z
- Vowels most frequently illegible:
  - a, e, i, o
- Vowel less frequently illegible:
  - u

(Ref: Coleman, 1970; Graham, 1986; Hanna, 1966; Horton, 1970; Lewis & Lewis, 1965; Newland, 1932; Pressy & Pressy, 1927)

B. Key

Underlined print = real word in Ginn Series First Grade Reading Word List

Regular print = nonwords created by changing first letter and using frequently illegible letters

{ } words created by changing vowel or by changing consonant in word beginning with a vowel

[ ] words created by changing first letter using letters that are frequently illegible but infrequently appearing as initial consonants

C. Nonwords

CV

go - bo, po, ro [ko, qo, zo] {ga, ge, gi, gu}
by - dy, gy, hy, jy, ny, py, ry, dy, ty [ky, qy, zy] {ba, be, bi, bo, bu}
me - de, ge, he, je, ne, pe, re, se, te [ke, qe, ye, ze] {mi, mo, mu}

VC

up - ap, ep, ip, op; ub, ud, ug, uh, un, ur, ut [kp, qp, yp, zp]

of - af, ef, if, uf; ob, od, oj, ot [ok, oq, oy, oz]
oh - eh, ih, uh
as - es, is, os {ab, ad, ag, aj, an, ap, ar} [ak, aq, ay, az]
am - em, im, om, um

CVC

did - gid, jod, nid, pid, tid [qid, yid, zid]
was - bas, das, jas, nas, pas, ras, sas, tas [kas, qas, yas, zas]
sad - jad, nad, rad [kad, qad, yad, zad]
leg - deg, heg, jeg, neg, reg, seg [qeg, yeg, zeg]
vat - dat, gat, hat [kat, qat, yat, zat]
cot - bot [kot, qot, yot, zot]
job - dob, hob, pob, tob [kob, qob, yob, zob]
rib - hib, nib, pib, sib, tib [kib, qib, gib, zib]
fog - gog, pog, rog, sog [kog, gog, yog, zog]
zip - bip, gip, pip [kip, qip]

CVCC

walk - dalk, galk, halk, jalk, nalk, palk, ralk, salk [kalk, qilk, yilk, zilk]
king - ging, hing, jink, ning [qing]
milk - dilk, gilk, hilk, jilk, nilk, pilk, rilk, tilk [kilk, qilk, yilk, zilk]
very - bery, dery, gery, hery, nery, pery, rery, sery, tery [kery, qery, yery, zery]
pond - dond, gond, hond, jond, nond, rond, sond, tond [kond, qond, yond, zond]
find - dind, gind, jind, nind, pind, sind, tind [qind, yind, zind]
down - bown, hown, jown, pown, rown, sown [kown, qown, yown, zown]
talk - dalk, galk, halk, jalk, nalk, palk, ralk [kalk, qalk, yalk, zalk]
back - dack, gack [kack, qack, zack]
worm - borm, gorm, horm, jorm, porm, rorm, sorm, torm [korm, qorm, yorm, zorm]
next - bext, dext, gext, hext, jext, pext, text, sext [kext, qext, yext, zext]
push - dush, jush, nush, sush [lext, qext, yext, zext]
call - hall, nall, rall, sall [kall, qall, zall]
fold - dold, jold, nold, pold, rold [kold, qold, yold, zold]
want - bant, dant, gant, hant, jant, nant, sant, tant [kant, qant, yant, zant]
lost - bost, dost, gost, jost, nost, rost, sost, tost [kost, qost, yost, zost]
went - hent, jent, nent [qent, yent, zent]
bird - dird, gird, hird, jird, nird, pird, rird, sird, tird [kird, qird, yird, zird]

hard - bard, dard, gard, jard, nard, pard, rard, sard, tard [kard, qard, zard]
song - hong, jong, nong, rong [qong, yong, zong]
warm - barm, darm, garm, jarm, narm, parm, rarm, sarm, tarm [karm, qarm, yarm, zarm]
very - bery, dery, gery, hery, hery, jery, nery, pery, rery, sery, tery [kery, qery, yery, zery]
girl - birl, dirl, hirl, jeil, nirl, pirl, rirl, sirl, tirl [kirl, qirl, yirl, zirl]
city - gity, hity, jity, nity, rity, sity [kity, qity, yity, zity]
both - doth, goth, hoth, joth, noth, poth, roth, soth, toth [koth, qoth, yoth, zoth]
pull - jull, rull, sull, tull [kull, qull, yull, zull]
high - bigh, digh, gigh, jigh, pigh, righ, tigh [kigh, qigh, yigh, zigh]

CVCV

fire - bire, gire, jire, nire, pire, rire [kire, qire, yire, zire]
made - dade, gade, hade, nade, pade, rade, sade, tade [kade, qade, yade, zade]
some - bome, gome, jome, nome, pome, rome, tome [kome, qome, yome, zome]
bone - done, hone, jone, none, rone, sone [kone, qone, yone]
bike - gike, jike, rike, sike, tike [qike, yike, zike]
were - bere, dere, gere, jere, nere, pere, rere, sere [kere, qere, yere, zere]
gave - bave, have, jave, nave, tave [kave, qave, yave, zave]
race - bace, dace, gace, hace, hace, nace, sace, tace [kace, qace, yace, zace]
ride - dide, gide, jide, nide, pide [kide, qide, yide, zide]
take - dake, gake, hake, nake, pake [kake, qake, yake, zake]
care - gare, gare, nare, pare, sare, tare [kare, qare, yare, zare]
give - bive, nive, pive, rive, sive, tive [kive, qive, yive, zive]
nice - bice, gice, hice, jice, pice, sice [kice, qice, yice, zice]
more - dore, hore, jore, nore, rore [kore, qore, yore, zore]

CCVC

drop - brop, frop, hrop, jrop, nrop, srop, trop [krop, qrop, yorp, zorp]
from - brom, drom, grom, hrom, jrom, nrom, srom, trom [krom, qrom, yorm, zorm]
swim - bwim, dwim, gwim, hwim, jwim, nwim, pwim, rwim, twim [kwim, qwim, ywim, zwim]
they - bhey, dhey, ghey, jhey, nhey, phey, rhey, shey [khey, qhey, yhey]

flew - dlew, glew, hlew, jlew, nlew, plew, rlew, tlew [klew, qlew, ylew, zlew]

CVVC

read - gead, jead, nead, pead, sead, tead [kead, qead, yead, zead]
mean - hean, nean, pean, rean, sean, tean [kean, qean, yean, zean]
beat - deat, geat, jeat, reat [keat, qeat, yeat, zeat]
your - bour, gour, jour, nour, rour [kour, qour, zour]
toad - board, doad, hoad, joad, noad, poad, soad [koad, qoad, yoad, zoad]
room - goom, hoom, joom, noom, poom, soom, toom [koom, qoom, yoom]
roof - boof, doof, good, joof, noof, soof, toof [koof, qoof, yoof, zoof]

VCVC

away - ewey, iwey, owey, uwey
eyes - iyes, uyes, oyes
ever - aver, iver, uver
open - apen, epen, ipen, upen

CCVCC

trick - drick, grick, hrick, jrick, nrick, srick [krick, qrick, yrick, zrick]
truck - bruck, druck, gruck, hruck, jruck, nruck, pruck, sruck [kruck, qruck, yruck, zruck]
trade - brade, drade, hrade, jrade, nrade, prade, srade [krade, grade, yrade, zrade]
thing - bhing, dhing, ghing, hring, jring, nring, pring, sring, tring [kring, gring, yring, zring]
climb - blimb, dlimb, glimb, hlimb, jlimb, nlimb, plimb, tlimb [klimb, qlimb, ylimb, zlimb]
white - bhite, dhite, ghite, jhite, nhite, phite, shite, thite [khite, qhite, yhite, zhite]
chick - bhick, dhick, ghick, jhick, nhick, phick, rhick, shick [khick, qhick, yhick, zhick]
shell - bhell, dhell, ghell, jhell, nhell, phell, rhell, thell [khell, qhell, yhell, zhell]
place - blace, dlace, glace, hlace, jlace, nlace, rlace, slace, tlace [klace, qlace, ylace, zlace]
which - bhich, dhich, ghich, nhich, phich, rhich, shich, thich [khich, qhich, yhich, zhich]
while - bhile, dhile, ghile, jhile, nhile, phile, rhile, shile, thile [khile, qhile, yhile, zhile]
start - btart, dtart, gtart, htart, ntart, ptart, rtart [kart, qart, yart, zart]

CVCCC

first - birst, dirst, girst, hirst, jirst, nirst, pirst, rirst, sirst, tirst [kirst, qirst, yirst, zirst]
happy - bappy, dappy, gappy, jappy, rappy, tappy [kappy, qappy]
songs - hongs, jongs, nongs, pongs, rongs [kongs, gongs, yongs, zongs]
right - bight, dight, gight, jight, pight [kight, qight, yight, zight]
lunch - dunch, gunch, junch, nunch, runch, sunch, tunch [kunch, qunch, yunch, zunch]
catch - datch, gatch, jatch, natch, ratch, satch, tatch [katch, qatch, yatch, zatch]

CVCVC

lived - bived, gived, hived, nived, pived, rived, sived, tived [kived, qived, yived, zived]
paper - baper, daper, gaper, haper, naper, saper [kaper, qaper, yaper, zaper]
raked - daked, gaked, haked, jaked, paked, saked, taked [kaked, qaked, yaked, zaked]
liked - diked, giked, jiked, niked, piked, riked, siked, tiked [kiked, qiked, yiked, ziked]
color - bolor, dolor, golor, holor, nolor, polor, solor, tolor [kolor, qolor, yolor, zolor]
woman - boman, doman, goman, homan, joman, noman, poman, soman, toman [koman, qoman, zoman]

CVVCC

doing - boing, hoing, joing, noing, poing, roing, soing, toing [koing, qoing, yoing, zoing]
found - dound, gound, jound, nound, tound [kound, qound, yound, zound]
house - bouse, gouse, nouse, pouse, rouse, touse [kouse, qouse, youse, zouse]
could - bould, dould, gould, hould, jould, nould, pould, rould, tould [kould, qould, yould, zould]
guess - buess, duess, huess, juess, nuess, puess, ruess, suess, tuess [kuess, quess, yuess, zuess]
woods - boods, doods, joods, noods, poods, roods, soods, toods [koods, qoods, yoods, zoods]

CCVCV

rhyme - bhyme, dhyme, ghyme, jhyme, nhyme, phyme, qhyme, shyme, thyme [khyme, qhyme, yhyme, zhyme]
place - blace, dlace, glace, hlace, jlace, nlace, qlace, rlace, slace, tlace [klace, qlace, ylace, zlace]

CCVVC

train - hrain, jrain, krain, nrain, prain, srain [krain, qrain, yrain, zrain]
great - breat, dreat, hreat, jreat, kreat, nreat, preat, sreat [kreat, qreat, yreat, zreat]
cried - bried, dried, gried, hried, jried, nried, pried, sried [kried, qried, yried, zried]

CVCCV

fence - bence, dence, gence, jence, nence, rence, sence, tence [kence, yence, zence]

CCVVC

floor - bloor, dloor, gloor, hloor, jloor, nloor, ploor, rloor, sloor, tloor [kloor, qloor, yloor, zloor]

APPENDIX C
SUBJECTS' SCORES

Word Spacing

0.5m-1-Wd	0.5m-2-Wd	0.5m-3-Wd	0.5m-4-Wd	0.5m-5-Wd	0.5m-6-Wd	0.5m-7-Wd
0	1	1.5	1.5	4	1.5	1
.5	1	1	.5	1	3	0
2.5	0	1	0	3	2.5	2
2	1	1	.5	4	1.5	2
2.5	0	1.5	.5	2	1.5	1.5
2	.5	.5	0	4	2	3
2.5	1.5	2.5	.5	2.5	.5	1.5
2	1	1	1	.5	2.5	1.5
2	0	2	.5	3.5	1.5	3
0	.5	2	0	3	2.5	2
0	1.5	.5	.5	3	3.5	2
.5	0	.5	0	3	2.5	2

3m-1-Wd	3m-2-Wd	3m-3-Wd	3m-4-Wd	3m-5-Wd	3m-6-Wd	3m-7-Wd
2	.5	1.5	1	2	1	1
0	.5	.5	0	4	2	3
1.5	0	1	.5	3	.5	2
1	1.5	1	.5	3.5	2	2
1.5	0	.5	1	4	2.5	1
.5	0	1.5	0	4.5	1	1.5
0	.5	1.5	0	3.5	2.5	1.5
1.5	.5	1	0	3.5	1.5	3.5
1	.5	1	0	2.5	1.5	3.5
1.5	1	1	0	4	1	3
1.5	1.5	0	0	4	2.5	4
1.5	1	1	.5	3	4	2

6m-1-Wd	6m-2-Wd	6m-3-Wd	6m-4-Wd	6m-5-Wd	6m-6-Wd	6m-7-Wd
.5	0	2	2	3	.5	1.5
0	.5	0	1.5	1.5	2	1.5
0	0	.5	0		2.5	2
1	1.5	1.5	.5	3	2.5	1.5
.5	.5	1	1	4	3.5	2
1.5	1	1	1	3	2	1
.5	1.5	.5	0	1.5	3	1
0	.5	.5	0	3	3.5	2
1	.5	1.5	0	3.5	2.5	2
.5	1	1	0	3.5	2	.5
0	.5	1	0	2.5	3.5	2
1.5	.5	.5	.5	2.5	2	1.5

0.5-8-Wd	0.5m-9-Wd	0.5m-10-Wd	0.5m-11-Wd	0.5m-12-Wd	0.5m-13-Wd
2	1	2	3	3	2
1	2	2	1	3	5
.5	2	2	4	4	3.5
1	2	1	1.5	3.5	2.5
0	4	2.5	2.5	3	4.5
0	2.5	1.4	2.5	2	4.5
1	2.5	2.5	1.5	1.5	1.5
0	2	1.5	1.5	3.5	3.5
.5	4	0	3	3	3
0	4.5	1.5	2.5	3	2.5
.5	2.5	3	1.5	2	3
0	3.5	2	1.5	2.5	3.5

3m-8-Wd	3m-9-Wd	3m-10-Wd	3m-11-Wd	3m-12-Wd	3m-13-Wd
1	2	2	2.5	3	2.5
.5	2	1	2	3	2.5
1	2.5	1	1	2.5	3.5
1	1.5	1.5	2.5	2.5	4.5
0	3	2.5	2	2	4
0	1.5	1	2.5	3	4
0	4	2	2	1	3
.5	3	2.5	2.5	1	4
0	3	2	2	2	3.5
0	3.5	.5	1.5	3	3
1	3.5	2	2.5	3.5	2.5
0	4	.5	1.5	2	2.5

6m-8-Wd	6m-9-Wd	6m-10-Wd	6m-11-Wd	6m-12-Wd	6m-13-Wd
2.5	1	1	3	3	4
0	1.5	1	3	3	2.5
0	1	1.5	3	3	4.5
0	4	1.5	3	2	2.5
0	2.5	1	2.5	3	3
.5	3.5	.5	2	3.5	3.5
0	4	2	2.5	3	4
.5	3	1	2.5	4	3.5
0	4	1.5	1.5	2.5	2.5
0	4	3	2.5	2	3
0	4	1	3	1.5	3
0	2	1.5	1.5	2.5	3.5

Letter Formation

0.5m-1-LF	0.5m-2-LF	0.5m-3-LF	0.5m-4-LF	0.5m-5-LF	0.5m-6-LF	0.5m-7-LF
67	32	29	48	87	40	82
38	30	34	46	86	64	90
42	20	35	47	91	87	105
56	21	37	40	84	84	113
84	16	31	50	84	84	100
74	20	40	59	86	77	85
98	34	35	46	66	61	101
88	36	36	52	73	61	110
88	26	55	34	88	55	100
64	15	46	44	81	49	97
89	25	38	34	85	72	91
58	32	29	47	72	77	96

3m-1-LF	3m-2-LF	3m-3-LF	3m-4-LF	3m-5-LF	3m-6-LF	3m-7-LF
52	29	49	40	91	47	66
30	27	45	43	84	68	80
61	27	39	45		58	76
73	28	36	44	83	85	97
94	22	31	52	102	78	100
57	30	47	43	98	65	81
92	26	49	40	89	71	93
93	18	37	53	102	62	108
75	30	42	53	81	60	105
61	28	30	63	87	41	106
67	32	39	38	79	87	108
84	38	22	51	84	85	100

6m-1-LF	6m-2-LF	6m-3-LF	6m-4-LF	6m-5-LF	6m-6-LF	6m-7-LF
38	35	40	34	99	43	46
58	11	39	45	77	90	74
40	34	40	34	89	71	100
55	36	33	42	79	73	95
54	23	38	47	88	90	85
74	22	30	46	70	70	88
72	45	21	37	84	81	74
61	21	33	53	85	71	92
67	21	33	41	77	47	103
67	28	29	56	78	43	76
78	25	27	38	86	90	93
73	38	33	44	74	74	108

0.5-8-LF	0.5m-9-LF	0.5m-10-LF	0.5m-11-LF	0.5m-12-LF	0.5m-13-LF
78	65	43	69	88	94
91	69	50	44	94	108
96	104	43	88	88	99
102	79	31	73	80	79
69	86	60	76	90	100
90	87	59	75	95	113
94	100	58	51	97	111
79	96	55	72	91	102
101	102	50	79	91	103
112	106	64	80	103	117
94	101	62	81	88	95
87	104	62	62	90	74

3m-8-LF	3m-9-LF	3m-10-LF	3m-11-LF	3m-12-LF	3m-13-LF
70	61	47	72	65	66
96	89	47	75	97	92
104	83	41	72	103	106
91	83	38	63	75	116
73	116	59	75	91	105
85	86	32	57	80	104
78	103	45	76	72	110
75	97	48	84	85	100
95	106	65	83	83	89
112	120	54	73	96	116
108	101	50	85	103	95
106	115	56	84	96	109

6m-8-LF	6m-9-LF	6m-10-LF	6m-11-LF	6m-12-LF	6m-13-LF
80	68	41	54	82	88
82	71	43	67	84	87
71	78	38	74	79	96
98	94	43	79	86	85
71	87	74	65	75	86
94	114	61	65	86	116
72	101	56	58	76	86
100	96	45	62	81	103
92	96	72	58	77	88
84	113	61	76	93	94
93	125	57	77	103	109
93	107	62	65	99	112

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BIOGRAPHICAL SKETCH

Kay Frances Walker was born July 22, 1942 in Branford, Florida, a small town in the northern part of Florida. She grew up on a farm with her parents, five sisters, and one brother. Elementary schooling was at a country school, Pickett Lake Elementary, and at Mayo Elementary in Mayo, Florida. She was graduated from Lafayette High School, Mayo, Florida, in June, 1960.

Ms. Walker received the Bachelor of Science in Occupational Therapy, in 1964, and the Master of Education in special education, in 1970, from the University of Florida, Gainesville, Florida. Professional work experience in occupational therapy included staff therapist and director of occupational therapy positions at Sunland Training Center, Gainesville, Florida, from 1964 through 1969. She has served as a faculty member in the Department of Occupational Therapy, College of Health Related Professions, University of Florida since 1971. In 1985, she was appointed Chairperson, Department of Occupational Therapy. In the future, Ms. Walker intends to continue her service to the University of Florida, in the Department of Occupational Therapy.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Mary K. Dykes, Chairman
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